ANNUAL CONVENTION TRANSACTIONS

FIFTEENTH ANNUAL CONVENTION

AMERICAN SOCIETY
FOR
QUALITY CONTROL

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FOREWORD

During the early years of the Society, its greatest strength lay in the Sections and Regional organizations, many of which antedated the formation of the national organization. The first four national conventions were held in conjunction with regional conferences (1947-1950).

A major step forward was taken in 1951 when, for the first time, the Annual Convention was held as an independent activity of the Society, completely divorced from any connection with regional conference. Under the leadership of Wade R. Weaver, the American Society for Quality Control began to emerge as an organization capable of serving the national interests of its members in ways beyond the limitations of section and regional groups. A General Convention Committee was created and given the responsibility to provide the long range guidance and planning needed to insure the programming and management of effective annual conventions. This Committee served the Society ably, as the record of nine consecutive conventions under its surveillance amply testify.

With completion of the 1959 Convention, the General Convention Committee was discontinued, thus completing a transition program begun a year earlier to pave the way for the next major step forward in convention management for ASQC, viz, the transfer of the business management of its conventions to the Society headquarters office and the program planning to a committee under the supervision of a vice-president of the Society. The 1960 Convention was the first one to be managed and programmed under this new administrative procedure.

These Transactions constitute a record of the presentations at the Fifteenth Annual Convention. They have not been subjected to review by the Editorial Board of the Society. The timetable for planning our conventions precludes this at the present time. After the Convention, the papers will be reviewed by the Editorial Board and certain of them may appear in Industrial Quality Control.

Request for permission to reprint any portion of these Transactions should be addressed to Professor Irving W. Burr, Chairman, Editorial Board, Statistical Laboratory, Purdue University, Lafayette, Indiana.

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Mason E. Wescott
Retiring Chairman, Editorial Board

HOW TO EVALUATE A COMPANY'S QUALITY CONTROL NEED

Leonard A. Seder
Leonard A. Seder and Associates

The object of this paper is to attempt to answer the question: "How does one evaluate a company's quality control need?"   Considering the wide varieties of products, sizes of companies and specific technological problems, one might well find it difficult to generalize.   There is no question, for example, that different companies have widely different types of quality problems, because of the varying nature of the products they make.   Moreover, their quality control needs vary widely, also, if we consider the word "need" in its narrow sense of specific need for particular measuring techniques, statistical methods, or process control devices.   However, if we consider the word "need" in its broader sense of functions, attitudes and philosophies then it does turn out that most companies' quality needs can be stated in similar terms.

Company Quality Objectives

This is so because, in the broad sense, most companies' quality objectives are similar.   A. V. Feigenbaum's statement of these objectives in his discussion of Total

Quality Control [1] is quite apt.   He says the objectives of a quality function should be:

1. To provide assurance that the company's products are right for the customer.
2. To assist in achieving Optimum Quality Costs for these products.

Assuming that these are, in fact, the company's objectives for its quality function, we shall discuss, in terms of these objectives, how to evaluate the quality control need of a specific company through the gathering and interpretation of certain key data, the interviewing of key individuals in the organization and the personal observation of the company's quality control functions in operation.

The intent will be to make the evaluation as objective as possible.   To this extent, certain yardsticks or rough rules of thumb will be suggested.   Slavish adherence to such yardsticks, however, is obviously dangerous.   These figures are not to be taken as "official" or the "national average".   In spite of the effort at objectivity, it is obvious that some factors must--at the present state of knowledge--remain subjective. In these areas, there is evidently room for differences of opinion, even among the "experts".   The discussion of such subjective factors herein must be considered as the opinions of the author.

We shall consider, then, such questions as:
A. How does one go about evaluating a company's quality control need?
B. What measurements can be made on the overall status that yield an opportunity to stack up the company's status against others?
C. What observations should be made to read the "pulse" of the organization?
D. What symptoms indicate the possible presence of underlying unsolved problems?

In effect, it is as though I were an elderly physician addressing other physicians some 50 or 60 years ago, before the development of modern diagnostic tests.   I am going to try to summarize my "vast" experience and tell you to take the patient's pulse, blood pressure and temperature, look down his throat, and up his nose, hammer on his knees, peer at his eyeballs, and how to come up with a diagnosis of appendicitis, liver ailment, rupture or what-not.   I do not really jest.   Some years from now--less than 50, I hope--we shall have much better tests and measurements for evaluating these quality control needs.   Today, our means are crude, but they are nevertheless worth discussing.

Much of what follows was learned through fortunate association with J. M. Juran, who has done the pioneering work and continues to lead our thought in these management areas.

Assurance Of Customer Satisfaction

Feigenbaum's first objective was "to provide assurance that the company's quality is right for the customer."   Note that this broad statement includes assurance of "quality of design" as well as "quality of conformance".   How, then, can we evaluate the company's achievement (or lack of it) with respect to this objective?   Clearly, we

need a measure of customer satisfaction.　More properly, the company needs such a measure, which is presented monthly to top management and used by them to guide decisions in the customer quality relations area.　The absence of such a measure is, in itself, a symptom, for its absence generally is accompanied by a disillusioned Sales Department, and by management stampedes on the basis of individual complaints.　From the manufacturing view, these are regarded as over-exaggeration of "isolated cases".　If no such measure exists, the first step in evaluation is to obtain it in one of several ways:

1. Determining the rate of rejection, return or complaint by customers.
2. Determining the field reliability of its product against desired goals and against competition.
3. Determining the actual outgoing quality by a customer-oriented sampling and performance testing against government, industry or self-imposed standards.

In addition to such direct measures, some indirect indicators of customer satisfaction are obtainable from:

1. The results of customers' "vendor survey team" reports.
2. The opinions of the company Sales Department people.
3. Interviews with actual customers, or ultimate consumers (when the two are different.)

Perhaps the most universal of these measures is that of the rate of customer return or complaint.　A few words are therefore in order about the preparation and interpretation of such data.

First, it must be recognized that returns and complaints are a valid measure of customer satisfaction only under particular conditions.　It is well known that the boiling point of the customer (i.e. the point at which he will return or complain in writing about an unsatisfactory product) varies directly with the price of the product and the economic climate.　Juran has pointed out that there is a 45° curve relating the "ratio of complaints to product failures" to the "unit price" of the product and that this curve shifts to the right in a seller's market, to the left in a buyer's market. In other words, the number of complaints received by a razor blade manufacturer will normally be 1/1000th or less of the number of "failures" in the product shipped, while the automobile manufacturer may receive 50% or so, and the missile-maker more nearly 100%.　All these numbers are smaller when the goods are hard to get.

This fact means that number of complaints are a valid measure of customer satisfaction only if the company's products are at the high end of the curve, whereas they are poor measure--because they are too insensitive to product quality changes--if the product is at the low end of the scale.　In such case, some other means must be found, such as outgoing product examination, to measure failures directly and thus to estimate probable customer satisfaction.

The complaint rates of various companies in different industries confirm this fact. The following is a tabulation from the author's experience.

TYPICAL COMPLAINT OR RETURN RATES

Consumer Products

Time to Consume or Wear Out	Typical Products	Typical Complaint Rate
Years	Appliances, autos, furniture, clocks, watches, cameras	1　-10　%
Months	Shoes, garments, cigarette lighters, medical products	.1　- 1　%
Days	Razor blades, candy, food, cosmetics, drugs	.001 - .05 %　(10 - 500 per million)

Industrial Products

Unsophisticated customers	.5　- 5　%
Sophisticated customers	1　-10　%

In preparing figures to measure a company's complaint rate, it is first important

to make sure that:

1. Sales Policy returns are excluded.
2. There is an unbiased classification of whether the customer or the product is at fault.

Beyond obtaining and evaluating such a specific measure as complaint rate, there are a number of other "subjective" factors which ought to be considered in order to arrive at a judgment as to whether the company is sensitive to customer needs and is alert to the advantages that can be had from plugging in to the stream of information that comes back from the users of the product.   The following is a symptom checklist to evaluate such alertness:

1. Is there a procedure for handling the customer who complains so that his dissatisfaction can be minimised?
2. Is there a formal procedure for investigating the cause of complaint, requiring an answer in writing that is sent to the customer or at least filed?
3. Are the accumulated complaint data summarised to detect chronic situations, to determine the effect of deliberate (or even accidental) changes in design or manufacturing methods, to learn of any peculiar geographic anomalies in the complaint rate, etc.?
4. Is all complaint information, including both individual complaints and analyses thereof, fed back to the internal company function that can take steps to remedy it?
5. Is there an alertness to the significance of an unusual complaint, even though it may seem to be an "isolated case" or otherwise not be statistically significant?   Such unusual complaints that "can't happen" may be highly important to the company's future quality reputation.
6. Is there an awareness generally of the principal categories of complaint? Do they match up with the principal causes of factory rejection?   If they do not, it may mean that unnecessary cost is being incurred to find defects the customer is not complaining about, while at the same time insufficient attention is being paid to the defects that really bother him.
7. In the case of industrial customers, have the standards for non-measurable defects been discussed and agreed to with the customer's quality control people?   Is there a method of transmitting this agreement to all the people who need to know it?
8. In the case of consumer products, have efforts been made to learn the real sensitivities of the customer, or are we instead depending on the opinions of the factory "experts" who are highly sensitised to defects in the product that the customer may not be able to see, or smell, or taste? If so, we may be unrealistically tight in attempting to achieve perfectionism without accompanying value.
9. At the other end of the scale, is the customer actually unreasonable in his quality demands?   It may actually be better not to do business with a customer who insists on standards or AQLs which are clearly well beyond our ability to meet.

Assurance Of Optimum Quality Cost

Feigenbaum's second objective was: "To assist in achieving optimum quality costs for these products."   Our survey of the company's quality control need must, then, concern itself with how well the optimum has been achieved or is being sought.

The first question is whether the company has a knowledge of its Quality Costs. The absence of such knowledge in reasonable detail is, in itself, a serious symptom. For it is obviously essential to have a continuing knowledge of Quality Costs if we are to talk about striving for an optimum Quality Cost.   Quality Costs are all of the costs and losses which exist because it is necessary to meet customers' requirements or quality specifications.   They are conveniently divided into:

Failures - The losses in scrap, rework, repair, discounts, returns associated with material which failed to meet requirements.

Appraisal - The costs of sampling, measuring, testing, segregating, sorting to appraise quality and to keep product streams "pure".

Prevention- The costs of planning, analysis, diagnosis, study and remedy-generation to improve existing or future quality levels.

The meaning of "optimum" Quality Costs requires an understanding of the economics of quality.   Failure costs are high when the conformance of product to requirements is poor; they decrease as better conformance is achieved.   Prevention costs, on the other

hand, rise as better and better conformance is sought.   Appraisal costs have aspects
of both behaviors.   Those Appraisal costs which are mainly sorting and segregating are
reduced with better conformance, while those Appraisal costs which are preventive in
nature tend to increase with better conformance.

We have, in effect, one curve which descends with improving quality, another which
ascends, and a third U-shaped curve.   The optimum occurs when the sum of the three
curves is at a minimum.   In other words, optimum Quality Cost is achieved when the sum
of Failure, Appraisal and Prevention costs is at a minimum.   This is a lot easier to
describe in theoretical terms than to determine in practice.   However, some approaches
which have been tried and some approximate indexes may be helpful.

The problem is, how do we know on which side of the minimum we are or whether we
are right at the minimum?   For that question, we have some approximate criteria:
1. Juran: When Quality Costs are in the range of $500 - $1,000 per
    productive employee per year, or higher, it is likely that the
    company stands to gain by spending more on Prevention.
2. Feigenbaum: Quality Costs exceeding 10% of Sales are usually
    reducible.   Moreover, if Prevention costs are less than 10%
    of the total Quality Costs, we can expect to reduce Failures
    and Appraisal by spending more on Prevention.

The decision to try to reduce Quality Costs by increasing the amount spent on Pre-
vention should not be made by comparing the company's performance with these indexes.
The absolute magnitude of the Failure and Appraisal Costs will, in themselves, justify
or not justify the cost of a program to reduce them.   It is useful, however, to know
that others have been successful in making such reductions at the levels indicated in
the foregoing figures.

How Prevention Money Should Be Spent
     These indexes do not tell the whole story, by any means, for the money being spent
on Prevention may not be spent in the best way.   In evaluating the company's quality
control need, therefore, we must go into further detail on how the Prevention money is
spent.

Here is a checklist of symptoms to look for that indicate whether an apparently
adequate Prevention budget is being used in the right way.   It will also be a useful
list if the Prevention budget is inadequate in order to check for missing items.
1. Is there a clean separation between those people who do the day-to-day
    decision-making and those people who do the long-range analytical and
    planning work necessary to Prevention?
2. Does the organizational structure recognize the essential principles of
    organizing for a breakthrough? In a word, is the team approach em-
    ployed in planning and following through the program?   (2)
3. Do the people assigned to Prevention recognize the five basic principles
    necessary to accomplishment of Prevention goals?   (3)
    a. Principle of Prevention
    b. Principle of Scientific Method
    c. Principle of Separating Vital from Trivial
    d. Principle of Staff Assistance
    e. Principle of Coordination
4. Are the chronic defects tackled, rather than the sporadic?
5. Is the distinction made between management-controllable and operator-
    controllable defects and is the appropriate program of improvement
    employed for each type?
6. Are the basic data, such as process capabilities, determined and made
    available to the engineering and planning functions?
7. Is adequate quality planning done on new products so that expensive
    fiascos are avoided?
8. For complex products, is there an independent evaluation of design
    before release to Production?
9. Are adequate steps taken to plan for reliability tests and data
    feedback?

Are Appraisal Costs Too High?
     We have indicated, then, how the question of achievement of optimum Quality Cost
can be evaluated in several ways—some of them objective and some subjective.   The
discussion thus far is based on a premise; namely, that the dominating element of Qual-

ity Cost is the Failure cost. This is the usual case, since Failure cost generally amounts to 70% or more of the total Quality Cost. Occasionally, however, one encounters a situation where the Appraisal cost is the dominating element of Quality Costs, amounting to more than half of the total. The question may then properly be raised as to whether we are beyond the optimum, or, in other words, are over-inspecting.

Here, indexes of the type often cited may do more harm than good, i.e. the type of index which is expressed in terms of:

$$\frac{\text{Dollars of Inspection Cost}}{\text{Dollars of Mfg. Cost}} \quad \text{or} \quad \frac{\text{Number of Inspectors}}{\text{Number of Operators}}$$

The fallacy here is the assumption that the Inspection cost should vary with the amount of productive effort, whereas, in fact, it should be primarily dependent on the frequency of failures, or the potential frequency of failures.

Instead of depending on such indexes, we should study the situation surrounding each of the major Appraisal costs, since the answer to our question will depend on the facts of the individual situations. We can divide the question into two basic situations:

1. When the Appraisal costs are mainly in sorting and segregating good from bad.
2. When the Appraisal costs are mainly in sampling, either of the process or the product.

The first of these is fairly easy to judge. When the major Appraisal costs are in detecting and removing defects, the cost of not removing them should be determined and compared with the existing cost of removing them. The cost of not removing them will usually be found to consist of repairs, wasted operations, teardown and rebuild, production-line downtime, field failures, customer returns and so on. The costs of such difficulties are usually calculable, and the inspection data gives a measure of the frequency with which such a difficulty will be encountered if the sorting operation is replaced with sampling or abolished altogether. The decision as to the need can then be made on a rational economic basis. It is important here not merely to determine the total frequency of such failures, but also the pattern in which they occur. A highly erratic pattern from lot-to-lot means that a sampling plan can be depended on to detect the bulk of them.

It is not quite so easy to judge whether Appraisal costs are excessive when they are mainly in sampling of the process or product. This is because the inspection may well be acting so as to prevent the incidence of defects which would otherwise result in Failure costs far exceeding the existing Appraisal costs. Thus, it is argued, we can't answer the question without experimenting in reduction of inspection, which may be at great danger. It is like debating the question of whether reducing the local police force by 25% would actually result in a significant increase in the crime rate. Reflection will indicate that this depends a good deal on the morality of the local citizenry. Under stress, some companies have tried the brute force method of arbitrarily eliminating or reducing such sampling inspection only to have the whole thing boomerang in time. The insidious thing is that such a move may appear to work when viewed in the short range, because the full effect is not apparent until the good habits engendered by the "policing" influences are slowly replaced with the bad ones of unbridled license.

A far better approach is to examine the facts surrounding the specific situations to see whether factors have been overlooked which will permit discriminating reduction in inspection. Here is a checklist of possibilities:

1. Is anything being done to prevent the recurrence of rejected lots? If not, can it be? This should inevitably reduce inspection costs.
2. Are rejected lots actually being accepted anyway, via a Material Review or similar procedure? If so, action to change the specifications is indicated and inspection costs may be reduced.
3. Is there a combination of the last two, viz. ultimate acceptance of rejected material and no action to prevent recurrence? The inspection cost in such instances is clearly a waste of money.
4. Is advantage being taken of good history? Is reduced or skip-lot inspection being used when failures are relatively rare?
5. Can the inspection be done earlier before the streams have become contaminated?
6. Can the inspection be done later without adding much to the Failure Costs?
7. If process sampling is being done and decisions made by inspectors,

could this not be better done by operators, at less cost and with
greater effect?

8. Can improvements be made in the basic efficiency of the inspection
operation?   Work simplification techniques are applicable to in-
spection as well as production operations.   Possibly automatic in-
spection is the more economic answer to a chronic defect situation
that has no hope of improvement.

In summary, the minimum amount of inspection is that amount necessary to verify
that quality _is_ and continues to be satisfactory.   Whether we are concerned with in-
coming, in-process or outgoing product, such verification should be able to be accom-
plished with an audit type of inspection rather than a lot-by-lot acceptance and re-
jection.   If more inspection than that is being done, it is either because the quality
does not continue to be satisfactory over a period of time or because Quality management
is not responsive to the changing conditions.   The conclusions are thereby obvious.

Other Evaluation Points

Other check points for evaluation include certain specific procedures and practices
which historically have been found to contribute to the meeting of the basic quality ob-
jectives.   If one or another of these is missing, it does not necessarily mean that
there is a need, but its absence should at least raise the question.   In each of the
following cases, the question is whether there exists an adequate plan, and, if so,
whether it is being carried out effectively.

1. A plan for control of the accuracy of measuring instruments and gages.
2. A plan for handling of deviations such that decisions are made at
higher levels and information is utilized for improvement.
3. A plan for learning the level of competitive quality.
4. A plan for conveying to production operators accurate information on:
which are the vital quality characteristics, what are the tolerances
on process variables and which process specifications are mandatory
and which optional.
5. A plan for conveying to vendors the results of quality measurements
obtained on their shipments.
6. A plan for providing management with an executive instrument panel
on quality.

All of these, and others I have omitted, add up to the need for a written manual
describing the company's practices in detail.   The manual is not only the proof that
the answers have been thought out, but it is also the way of progressing from "govern-
ment by men" to "government by law."

Evaluation Of Intangible Factors

Thus far, we have considered a company's quality control need as expressed in
terms of its basic quality objectives, as defined herein.   Insofar as possible, we
have tried to consider either the basic economics or some other fairly tangible factors.
There are, however, a number of other factors which have an effect on the achievement of
the company quality objectives and yet are not measurable or tangible.   There are, for
example, the questions of organization for quality, the managerial and statistical com-
petence of the key individuals in the organization, and the general state of quality
morale.   That these factors have an important effect on the achievement of quality ob-
jectives is undeniable, yet there is also room for considerable difference of opinion in
evaluating the company's adequacy in these areas.

Despite such differences in opinion, there is need to set down some fundamental
needs in these areas.   By implication, the company which has not faced up to these
needs should be urged to do so.

With regard to organization for quality, experience has shown that there are many
different forms of organization which can successfully accomplish the objectives.   It
is not so much the form of organization that needs critical evaluation as it is the
question of whether the company has a sound plan of satisfying its basic organizing
needs.   These basic needs are set forth below.

1. Organization for Product Approval – With some few exceptions, there is
usually a need for "last word" approval of product for shipment to cus-
tomers to be done by a group which is independent of the people responsi-
ble for making the product.   The absence of such an independent final
inspection will usually be found to be the underlying cause of the symp-
toms of:
a. A higher-than-necessary level of customer dissatisfaction because of
the tendency of the "maker" to solve day-to-day delivery and cost

       problems at the expense of quality.

    b. Lack of adequate data for feedback to prevent recurrence, to identify major quality problems, to furnish executive reports on quality.

    c. A morale problem as the result of frustration on the part of those seriously attempting to control process quality.

2. Organization for Process Control - There is a need for the clear delegation of authority for making quality decisions during manufacture to the end that everyone involved knows and understands his responsibilities. To be at all effective, this must usually be a written delegation, embodying clear statements as to:

    a. Who decides whether a machine or process shall commence, or continue, to run? His is the responsibility for defects made.

    b. Who decides that lots or batches emerging from an operation may continue or to have the next operation performed? His is the responsibility for defects missed.

3. Organization for Solving Long-Range Problems - There is a need for one or more individuals, depending on size, to be free from the day-to-day activities to devote their efforts to the identification of the major chronic quality problems, to the development of programs to solve these problems, and to the planning of quality on new products so as to avoid these problems in the future. The absence of a separate person or group so charged means that it is unlikely that these jobs are being done, so that the company is, at best, just "holding its own" without making any significant progress in the quality area.

4. Managerial and Statistical Competence - There is a need for a Quality Manager who has the broad perspective of Total Quality Control, as opposed to great skill in any one of the particular techniques for achieving it, and who has demonstrable ability as a manager. The extent of statistical skills needed in the organization depends to a large extent on the size and type of quality problems encountered, but seldom is the total absence of these skills tolerable in today's competition.

5. Quality Morale - There is always the need for a high level of quality morale throughout the organization. No company can long survive the widespread conviction among its employees that "management" or some powerful group within management "does not really care about quality." The causes for such conviction are many and sometimes fairly complex. Among the more common are:

    a. Lack of a clearcut management policy on quality.

    b. Habitual exceeding of product specifications without penalty or alarm.

    c. Obvious fluctuation of quality standards with changing inventories or production schedules.

    d. Daily exposure to management decisions which are unashamedly directed to taking chances on the shipping of marginal quality.

    e. Constant pressure on operators for improvement when it is obvious to them that the major improvement can be made only by some action on the part of management.

The Essence Of Evaluation

In summary, we have looked at a number of checkpoints for evaluating a company's quality control need. The main headings were:

1. How well is the customer being satisfied?
2. Is enough Prevention Money being spent to avoid uneconomic Failure costs?
3. Is real Prevention being done through proper organizing and competency of people?
4. Is amount of inspection appropriate?
5. Is the organization for quality well thought out and does it satisfy basic needs?
6. Is there good level of quality Morale?

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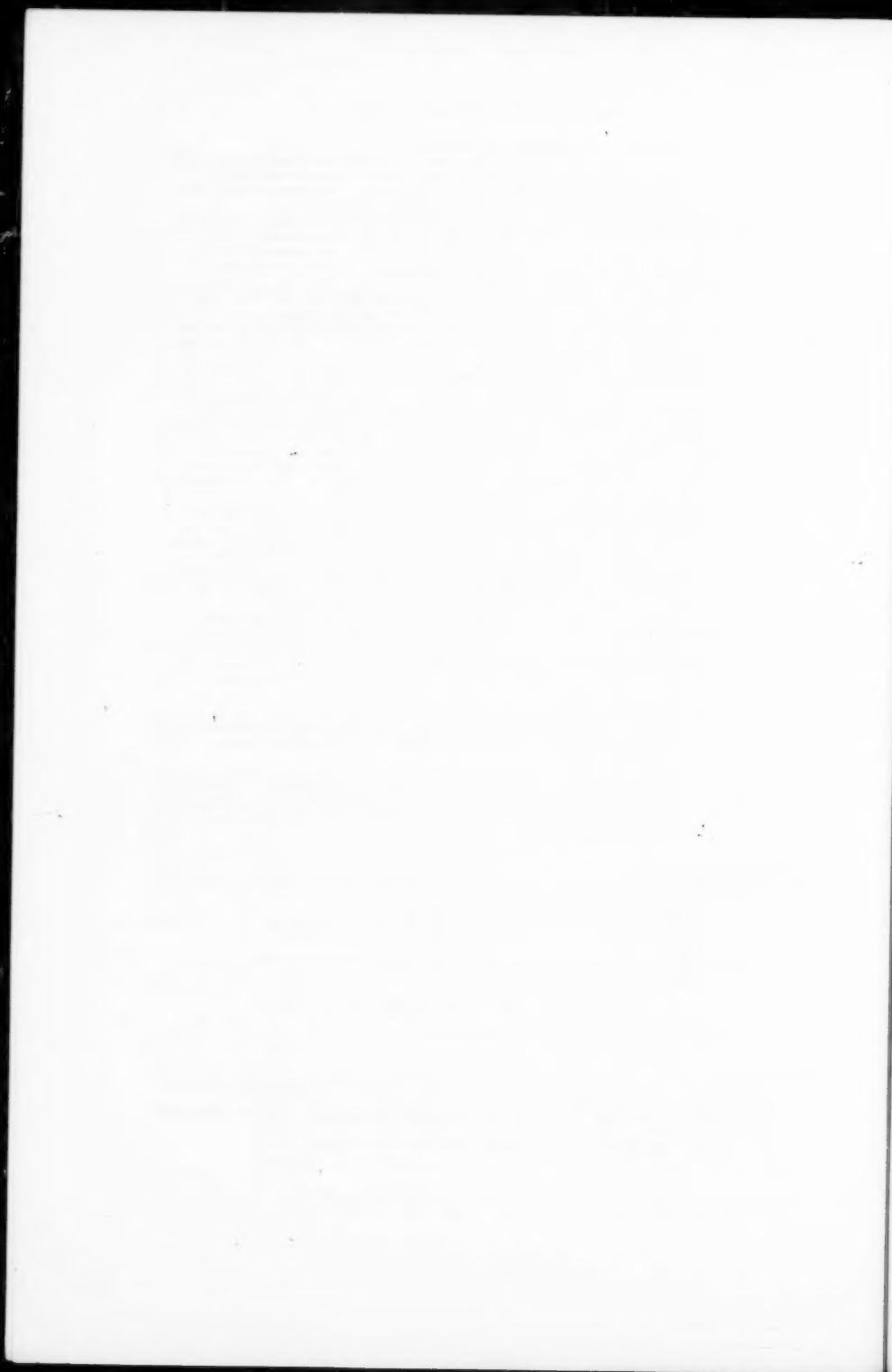
QUALITY COST CONTROL

Warren R. Purcell, Director of Quality Control
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From modest beginnings as a new field of activity on the industrial scene, Qua. ity Control has developed into a major engineering profession. It started with the technique of the control chart; it now encompasses the planning and administration of the entire quality control system, starting with the design review and continuing through incoming material control, process control, and finished product acceptance to the processing and analysis of data on field results and the monitoring of corrective action. It started with the application of scientific sampling to inspection; it now covers the design and construction of inspection and test equipment, its calibration and maintenance, the planning and implementation of its use, and breakthroughs to new frontiers in the field of measurement. It started by reporting "out-of-control" conditions; it now provides special skills needed to diagnose the quality ills of a process and develop and apply practical remedies.

Yet, in spite of the breadth and depth of the Quality Control profession, its objective can be stated in simple terms: Satisfactory Quality Assurance at Minimum Quality Cost. "Quality Assurance" is here defined as assurance that the customer will be satisfied with the quality of the product; "Quality Cost" as the cost of providing that assurance.

In our quality control activities do we always keep this objective in mind?

We assure conformance to engineering specifications. Does this necessarily assure conformance to customer requirements?

We administer sampling inspection with risks which can be mathematically calculated. But are those risks right for the needs of the business?

We quite properly survey the quality capabilities of a new, untested vendor. But should periodic surveys of his quality control facilities and procedures be continued in spite of existing objective evidence of his quality results? Such periodic surveys consume many man-hours of highly skilled personnel of both parties. Is this the most effective use of those skills? Would it be more effective to devote at least part of those many man-hours to, for instance, defect prevention programs?

We "hold costs down" by offering a limited salary, thereby recruiting an ineffective quality control engineer. Would a salary $5000 higher attract a man who could effectively help in reducing scrap loss by $100,000 a year each year?

The list of such questions could be extended. Some are related to "Quality Assurance", some to "Quality Cost", some to both. Unless we provide measures of Quality Assurance and Quality Cost, the effects of the decisions we make in answer to such questions cannot be evaluated objectively.

It is not the purpose of this paper to discuss at length various methods of measuring Quality Assurance. Suffice it to say that some satisfactory measure must be provided, since "Satisfactory Quality Assurance" is vital for the survival of any business. Low Quality Cost without Satisfactory Quality Assurance would indeed be an attainment signifying nothing.

Nevertheless, once Satisfactory Quality Assurance has been attained and is continuously verified, reduced Quality Cost is, for many businesses, a major potential for reduction of manufacturing costs.

The reason is the rapid increase in quality cost which has been taking place in many businesses for several years and is continuing today. There are many factors contributing to this increase.

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One factor is the increase in product complexity. Because of the interdependence of parts and the consequent compounding of probabilities, the increase in quality problems is greater than the increase in the number of parts in an assembly. Thus as product complexity increases, the ratio of quality cost to total manufacturing cost increases.

Another factor is the increase in precision requirements. We now talk glibly of millionths of an inch. We thus press the state of the art, not only in meeting microscopic precision, but also in measuring adequately to verify the fact.

Another factor is the increase in reliability requirements. The problem caused by this factor is not only the challenge of attaining high levels of reliability, but also the enormous cost of test-hours required to prove that it has been attained.

Another factor is the increase in specification complexity, which presents problems above and beyond those of product complexity. Many modern specifications, for instance, not only spell out the requirements of the product, but also legislate in detail the manufacturing and quality control system under which it will be built. And that is only the beginning. The contract calls out several specifications, each of which calls out several other specifications, each of which calls out several other specifications, and so on, in chain letter fashion. Conformance requires not only engineering and manufacturing skill, but a legal mind as well.

Because of these and other factors, quality cost has become, for many businesses, a major part of manufacturing cost. Furthermore, a large part of the quality cost may be significantly reducible. Whether such reductions result primarily in price reductions or profit increases, the long-term results are bound to improve the health of any business.

      *   *   *

Quality cost has been here defined as the cost of providing satisfactory quality assurance. Such a definition is, however, an over-simplification, and leaves many questions unanswered.

For instance, we have seen "quality cost" fugures which are simply the expenses incurred in running the quality control department. As such, they are an attempt to measure the expense of doing quality control work. But since the functions covered by quality control departments vary widely from company to company, and even from plant to plant within companies, the expression "quality control work" remains ill-defined. Furthermore, such figures exclude, for instance, the losses due to scrap and rework, which are surely part of the cost of providing assurance that the customer will be satisfied with the quality of the product he receives.

On the other hand, figures on "quality loss" have been used somewhat extensively. These figures measure the saving which would be made if no defects were generated. As such, they provide a good measure of progress in a project of limited duration and scope. But they hardly provide complete long-term control, for they do not include the expense of doing quality control work.

At Raytheon the following decisions were made: (1) the costs of doing quality control work, whether done by the quality control department or any other department or departments, are included in a classification called "quality expenses", (2) the costs of all defect-caused losses are included in a classification called "quality losses", (3) "quality cost" is the sum of "quality expenses" and "quality losses". *

* See W. J. Masser, "The Quality Manager and Quality Costs". INDUSTRIAL QUALITY CONTROL, Vol. XIV, No. 4, October, 1957, Pages 5 - 8. The Raytheon system is similar to the General Electric system, except that Raytheon's "expense" is the sum of General Electric's "prevention" and "appraisal", and Raytheon's "loss" is the same as General Electric's "failure".

To define "quality control work", Raytheon has written a carefully defined list of work elements, reproduced in Appendix A, QUALITY CONTROL WORK ELEMENTS. This has provided simplicity in an otherwise difficult area. By means of this it has been possible to evaluate "quality expense" with comparative uniformity.

It has been found desirable to simplify, as far as feasible, the regular periodic reports of total quality cost. This is to avoid any significant addition to quality costs caused by the work of measuring them.

For this reason the regular periodic reports contain no breakdowns other than the elements required to build them up. Thus, for instance, in the regular periodic reports no attempt is made to separate detail inspection from sampling inspection; they are both included in "Inspection", which is one of the elements of "Quality Expense". If this element is subsequently disclosed to be a significantly reducible one, as it frequently is, it can then be broken down into sampling and detailing, or into whatever other sub-classifications may seem most promising in the search for potentially significant reductions.

The use of a report form without fine breakdowns for regular periodic reporting of total quality cost has proved to be a fortunate breakthrough in simplification and consequent universal acceptance of the principle of quality cost reporting.

The reason lies in the fact that the forty work elements defined in Appendix A, QUALITY CONTROL WORK ELEMENTS, are a description of the functions of an "idealized" quality control department. If they are the work elements of the actual quality control department, then the operating expenses of that department, already being reported by regular accounting procedures, constitute the total of the "Quality Expenses". Insofar as part or all of some of the work elements are performed by other departments, the costs of those work elements are estimated. Then the total "Quality Expense" is the sum of the operating expense of the quality control department and the expenses of the work elements performed by the other departments.

"Quality Loss" is the sum of the defect-caused losses which fall into the categories of scrap, rework, downtime, downgrading, and warranty. There is usually general agreement that it is worth while to evaluate and report such losses anyway, even if the subject of "Quality Cost", as such, had never been brought up.

The items of the regular periodic quality cost report appear as shown in Appendix B, QUALITY COST REPORT FORM. While many of these items are self-explanatory, the following clarifying comments are offered:

2. Adjustments - The purpose of this is to take due account of any oddities encountered. For instance, if Safety Engineering is done by the Quality Control Department, the expense of this work is credited. Again, if some inspection work is charged to no department, but to general overhead, the expense of this work is debited.

4. Special Materials and Equipment - If capital inspection or test equipment is not included in Item 1., it is included here. The amortization value is debited for each month. Special treatment is used for capital equipment paid for by the customer.

5. Quality Expenses Other Departments - Here are listed the other departments, such as Production, Factory Engineering, etc., which do work described in Appendix A, QUALITY CONTROL WORK ELEMENTS. The cost of such work performed by each of such departments is estimated and debited.

9. Downgrading - This is the loss due to selling of the product at a reduced price because of failure to meet one or more of the product specifications. The amount debited is the price difference.

10. Downtime - This is the cost of idle time of machines, processes and operators caused by the fact that the machine or process has been making defective product and has been shut down for adjustment or repair. It does not include regular maintenance, nor does it include downtime caused by lack of good material from a vendor or previous process.

17. Percent 12 to 15 - This is the ratio of Total Internal Quality Costs to Cost of Manufacture. It is the measure watched most closely, since it reflects accurately the immediately-controllable quality costs.

18. Percent 13 to 14 - This is the ratio of Warranty Costs to Total Quality Costs. This ratio provides some measure of Quality Assurance, although it may be greatly influenced by market conditions.

19. Percent 14 to 16 - This is the ratio of Total Quality Costs to Sales. It is the ultimate measure of Quality Costs. But it is a statistic in which the time factor causes instability. Internal quality costs are incurred during the period being reported. Warranty losses and Sales which occur in one period are frequently the result of events which occurred in some earlier period.

A periodic quality cost report is issued once each quarter. The figures for each quarterly report are the combined results of three sets of monthly figures.

Thus the data are in form for control chart presentation, in that each group of three monthly figures forms a rational subgroup. Therefore the quality cost records are kept as control charts. The control limits indicate the maximum fluctuation which may be expected to result from the chance combining of the many small variables which affect such accounting figures.

This is a valuable asset, in that it prevents the constant chasing of rainbows which can result from watching the month-to-month fluctuations. The control limits in each case indicate the inherent instability of the statistic being charted. Thus the control limits for the ratio of Internal Quality Cost to Cost of Manufacture are not wide. This points out the relative precision of this statistic as a quarterly control figure. On the other hand, while the ratio of Total Quality Cost to Sales has the advantage of including Warranty Loss, which definitely must be watched, the statistic tends to be "out-of-phase" with Internal Quality Costs, and thus has relatively wide control limits.

It may appear to some that even the ratio of Internal Quality Costs to Cost of Manufacture, being published only once each quarter, is a too-long-delayed figure. This, however, misses the heart of the Quality Cost Control concept.

For the long-term control of quality costs is not simply a supplement to the day-to-day trouble shooting so characteristic of many existing programs. It is an attack on the enduring causes of high quality costs. It is in these enduring causes that the major potentials for quality cost reduction are found.

                    *   *   *

While most of the problems and rewards of conducting a total program of quality cost control are yet to be experienced, some characteristic patterns of progress are now emerging. A discussion of the patterns may be enlightening.

At the outset many express surprise that the quality costs are so high, in spite of advance estimates which may have been made. Facing up to the actual high dollar figures is a new experience. There is a new level of attention to the quality cost problem. Questions are asked. Are we doing too much inspecting and testing? Are our standards too strict? Are there duplications of effort? Are there too many layers of supervision in the quality control department? Is scrap being watched closely on a day-to-day basis?

Admittedly, wrong answers to some of these questions may generate ill-advised projects. Some such projects might have the net effect of increasing, not decreasing, quality costs. Some might jeopardize quality assurance. The Quality Control Manager must act as a brake on such decisions. But many of the questions do generate worth-while projects. These should be pursued to completion. In this way initial reductions in quality cost can be made without extensive analysis of quality cost figures and without the use of highly specialized managerial, engineering, or statistical techniques.

After a few months this initial program of projects runs its course. Significant reductions in quality cost appear. At best, quality costs then level out at a reduced plateau. At worst, they begin to rise again. This may be due to the introduction of

new products and the attendant problems, in which case renewed quality cost reduction efforts are called for. On the other hand, it may be because the reductions were not accompanied by adequate controls. The necessity of installing adequate controls to hold the gains is a constant requirement and the danger of overlooking this point is always present.

After the plateau has been reached, a more careful selection of further cost reduction projects is made. This is done by further analysis of quality cost. In this analysis the broad classifications of the quarterly reports are broken down into finer classifications by product lines, types of defects, cost centers, etc.. From among these classifications, further projects for cost reductions are selected on the basis of optimum combinations of (1) dollar loss and (2) ease of reduction of loss. The specialized techniques of quality control management and quality control engineering are applied as needed in the pursuit of these projects. Further reductions in quality cost are realized. Again the controls required to hold the gains are of the utmost importance; otherwise quality costs will climb again.

After many months a point is reached at which it may seem that little can be done to bring about further significant reductions in quality cost. At this point there may be, for instance, a few chronic defects still causing large loss, but they are considered "state-of-the-art" problems. They are, in fact, tough nuts to crack. Yet even many of these problems yield to the advanced techniques of quality control engineering, such as the tolerance analysis, the designed experiment, and the correlation study. If these advanced techniques are skillfully handled, new information on natural tolerances and on cause-and-effect relations can point the way to new breakthroughs in quality cost reduction.

*   *   *

Thus there is a logical sequence to Quality Cost Control. We start with the premise that the objective of quality control is Satisfactory Quality Assurance at Minimum Quality Cost. It then becomes apparent that the making of good quality-control decisions requires meaningful measures of the attainment of this objective. One of the meaningful measures is Quality Cost. Measuring and reporting of Quality Cost generates programs of reduction and control of this cost. The gain from this reduction and control may be very high, in many cases yielding a profit improvement comparable to that to be expected from major increases in manufacturing plant and sales, or price reductions which will substantially improve the company's competitive position.

APPENDIX A

QUALITY CONTROL WORK ELEMENTS

WORK ELEMENT	DEFINITION
1. Design of Inspection Equipment	An activity which plans the construction of gauges and fixtures to be used for measuring dimensional and visual characteristics of materials, parts, assemblies, and finished products.
2. Design of Test Equipment	An activity which plans the construction of apparatus to provide required inputs and measure resulting outputs of materials, parts, assemblies, and finished products.
3. Construction and/or Procurement of Inspection Equipment	An activity which makes or procures gauges and fixtures used to measure required dimensional and visual characteristics of materials, parts, assemblies, and finished products.
4. Construction and/or Procurement of Test Equipment	An activity which makes or procures apparatus to provide required inputs and measure resulting outputs of materials, parts, assemblies, and finished products.
5. Calibration of Inspection Equipment	An activity which compares and adjusts or correlates dimensional and optical measuring devices to standards.
6. Calibration of Test Equipment	An activity which compares and adjusts or correlates input-output measuring devices to standards.
7. Maintenance of Inspection Equipment	An activity which keeps dimensional and optical measuring devices in working condition.
8. Maintenance of Test Equipment	An activity which keeps input-output measuring devices in working condition.
9. Training of Inspectors	An activity which trains inspectors in the techniques of inspecting materials, parts, assemblies, and finished products.

10. Training of Testers

An activity which trains testers in the techniques of testing materials, parts, assemblies, and finished products.

11. Inspection of Incoming Materials

An activity which verifies that materials, parts, and assemblies procured from outside the facility for inclusion in the finished product meet required dimensional and visual characteristics.

12. Test of Incoming Materials

An activity which verifies that materials, parts, and assemblies procured from outside the facility for inclusion in the finished product meet required input-output characteristics.

13. Inspection of Work in Process

An activity which verifies that parts and assemblies produced within the facility for inclusion in the finished product meet required dimensional and visual characteristics.

14. Test of Work in Process

An activity which verifies that parts and assemblies produced within the facility for inclusion in the finished product meet required input-output characteristics.

15. Inspection of Finished Products

An activity which verifies that finished products meet required dimensional and visual characteristics.

16. Test of Finished Products

An activity which verifies that finished products meet required input-output characteristics.

17. Special Inspection and Test

An activity which verifies by means of visual, mechanical, chemical, physical, electrical, and other inspections and tests that processing materials not included in finished products meet specifications.

18. Disposition of Discrepant Material

An activity which decides whether to rework, screen, use-as-is, scrap, downgrade or otherwise dispose of discrepant materials, parts, assemblies, and finished products.

19. Failed Parts Analysis

An activity which determines the kind and cause of failure of materials, parts, assemblies, and finished products.

20. Inspection of Product Packing

An activity which verifies that products to be shipped to customers are identified, packed, loaded, braced, and routed as required.

21. Test of Product Packing

An activity which verifies, after engineering tests, that the specified containers and packing materials protect the product adequately against damage and deterioration.

22. Appraisal of Quality of Finished Products

An activity which evaluates the finished products to determine how well the products being shipped meet customer requirements.

23. Establishment of Quality Standards

An activity which specifies, by means of documents and physical specimens, required appearance characteristics of materials, parts, assemblies, and finished products.

24. Writing Quality Control Manuals

An activity which initiates and revises documents that describe the quality policies and quality operating procedures of the facility.

25. Inspection Planning

An activity which determines the location of inspection points, the kind and amount of inspection to be performed, the procedures to be followed, the characteristics to be measured, the equipment to be used, the forms to be used, and the records to be kept.

26. Test Planning

An activity which determines the location of test points, the kind and amount of test to be performed, the procedures to be followed, the characteristics to be measured, the equipment to be used, the forms to be used, and the records to be kept.

27. Maintenance of Quality Records

An activity which collects, sorts, summarizes, files, and maintains inspection and test data on materials, processes, parts, assemblies, and finished products.

28. Processing and Reporting of Quality Data

An activity which plans and performs the analysis and synthesis of inspection and test data on materials, processes, parts, assemblies, and finished products.

29. Trouble Shooting Sporadic Quality Problems

An activity which investigates day-to-day quality problems, isolates the immediate causes, and recommends immediate corrective action.

30. Investigating Chronic Quality Problems

An activity which investigates long-range quality problems, isolates the basic causes, and recommends permanent corrective action.

31. Follow-up of Corrective Action

An activity which monitors and reports progress in the implementation of solutions to quality problems and measures their effectiveness.

32. Appraisal of the Quality Control System

An activity which evaluates the Quality Control organization and procedures to determine their adequacy in meeting customer quality requirements at minimum quality cost.

33. Quality Cost Analysis

An activity which breaks down the facility's quality costs into meaningful classifications and points out areas of maximum potential reduction.

34. Vendor Quality Evaluation

An activity which evaluates the quality capabilities of a vendor from past performance and vendor facility reviews.

35. Contacts with Vendors on Quality Problems

An activity which works with vendors in eliminating non-conformance to required characteristics of supplied materials, parts, and assemblies.

36. Tolerance Review

An activity which reviews tolerances on the specified quality characteristics of materials, parts, assemblies, and finished products to determine whether they genuinely represent the limits of acceptability.

37. Quality Review of Customer Requirements

An activity which compares specified or implied customer requirements with the process and product capabilities of the facility.

38. Field Failure Analysis

An activity which determines and classifies the causes of failure of finished products which have been delivered to customers.

39. Quality Review of Product Specifications

An activity which compares written or implied product specifications with customer requirements.

40. Customer Contacts on Quality Problems

An activity which works with customers in eliminating non-conformance to required characteristics of finished products.

APPENDIX B

QUALITY COST REPORT FORM

	MONTH_____		
	DEBIT	CREDIT	NET
1. Reported Q. C. Department Expenses	_____	//////	
2. Adjustments	_____	_____	
3. Adjusted Q. C. Department Expenses			_____
4. Special Materials and Equipment			_____
5. Quality Expenses Other Departments			
5.1 _____	_____	//////	
5.2 _____	_____	//////	
5.3 _____	_____	//////	
5.4 Total Quality Expenses Other Departments			_____
6. Total Quality Expenses			_____
7. Scrap	_____	//////	
8. Rework	_____	//////	
9. Downgrading	_____	//////	
10. Downtime	_____	//////	
11. Total Internal Quality Losses			_____
12. TOTAL INTERNAL QUALITY COSTS			_____
13. Warranty Costs			_____
14. TOTAL QUALITY COSTS			_____
15. COST OF MANUFACTURE			_____
16. SALES			_____
17. PERCENT 12 to 15			_____
18. PERCENT 13 to 14			_____
19. PERCENT 14 to 16			_____

QUALITY AND RELIABILITY MANAGEMENT

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The tremendous cost of unreliable military equipment in a peacetime situation and the possible cost of national survival in wartime have caused the inclusion of firm reliability requirements in development and procurement documents. That portion of the commercial industry working on the research, development and production of systems for the control of continuous processes is rapidly recognizing the necessity of providing highly reliable equipment. Reliability has become a topic meriting the attention of top management so as to arrive at the most effective means of planning, organizing, directing, coordinating, and controlling a reliability assurance program. A reliability program will be suggested starting at the first concept of a product and continuing through development, production, and customer use of a product. The discussion will be restricted to the level of a plant with development, design, purchasing, manufacturing, and field service capabilities and responsibilities.

With reliability becoming prime product characteristic meriting attention from the cradle to the grave (first concept to field obsolescence) the combination of Reliability Engineering with Quality Control in an operating division on a level with Engineering and Manufacturing has much merit. Figure 1 presents an abbreviated organizational chart including a Reliability and Quality Division.
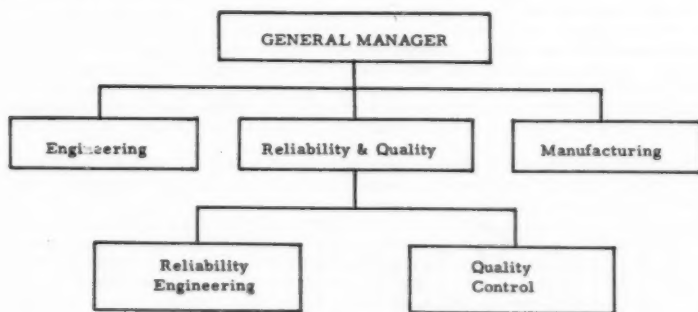

Figure 1

Advantages of a Reliability and Quality Division include:

    a. Reporting on a management level where opinions can be given the most complete consideration.

    b. Representation on the policy making team.

    c. Separate budget planned at the proper time to assure that effort is accomplished on a timely basis.

d. Recognition of the importance of quality and reliability as primary product characteristics.

The organization for reliability assurance has logically been divided into two parts, corresponding roughly to the development and production stages of a product. The logical assignment of reliability functions can be partially inferred from Figure 2.
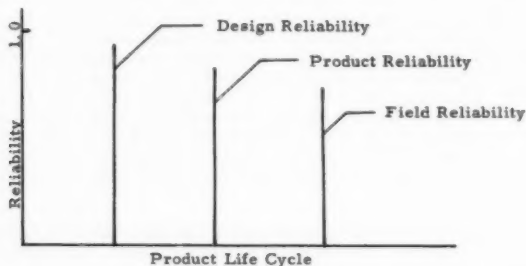

Figure 2

The design reliability demonstrated by the test of a prototype system built under model shop conditions provides a check on the success of the development effort and should be a significant factor in the decision to initiate factory production. The responsibility for assurance that the reliability of the design turned over to production satisfies the customer requirements is a Reliability Engineering task. This must not be misconstrued as an encroachment of the designer's responsibility. Engineering Design must be responsible and accountable for the design reliability.

The product reliability demonstrated by controlled tests of systems built in the factory with hard tools and production procedures can give a better indication of the reliability to be expected when the system is operated by the customer. Careful test planning is required to assure this result. Traditionally, Quality Control organizations have had the responsibility of assuring that the product agrees with the drawings and the specifications. It is logical then that Quality Control should have responsibility for the reliability of the product shipped from the factory. The difference between the design and product reliability is not only a measure of the quality of workmanship and effectiveness of Quality Control but also represents the producibility of the engineering design and the coordination of the Reliability Engineering and Quality Control efforts.

The planning of the reliability program will be discussed on the basis of areas of primary interest to Reliability Engineering, to Quality Control and of mutual interest. The Reliability Engineering planning must start at the earliest possible moment in a proposed program. This is necessary as early decisions can set an upper limit on system reliability. As an example, consider a complex system requiring a central computer which could be analog or digital. The analog computer could be implemented by mechanical, electro-mechanical and electronic types. Digital computer implementations include general purpose, differential analyzer, and functional technique types. Using the same rules with regard to component part selection and applications relatively crude absolute reliability predictions can be used to establish good relative indications of the reliability potential of the various possible computer implementations.

The development and application of reliability prediction techniques at the block diagram, schematic drawing and prototype hardware stages of a system development is an essential part of a Reliability Engineering effort. In order to develop, apply, measure the effectiveness, and refine the prediction techniques; studies in the following areas should be planned on a continuing basis:

    a. The relationship of component part failure modes and failure rates to circuit and system malfunctions.

    b. The effect of the complete environment on the performance of systems, circuits and component parts.

    c. The relationship to reliability of redundancy at the component part, circuit, and multimode system levels.

    d. The control of reliability tests on component parts, units and systems and the statistical analysis of the test results.

    e. The analytical relationship of controlled laboratory reliability tests to the field reliability experienced by the customer.

The implementation of these studies defines the responsibilities of the Reliability Analysis group shown in Figure 3.

The common practice of building a breadboard to prove the feasibility of a concept can lead to difficulty if reliability has not been considered. Top level scientists and engineers can usually get any system to work long enough to demonstrate to the sales force and potential customers. Demonstration of new capabilities or significantly higher performance then creates a demand for the system and pressure for a drastically short time to production. As a consequence, a production engineered version of a breadboard utilizing untested component parts often goes into production. The planning of continuing efforts in the selection and application of component parts is an essential reliability effort.

The selection, application and certification of component parts requires a group normally called Component Part Engineering. The selection of component parts requires a continuous monitoring and evaluation of new component parts as developed by parts manufacturers. The selection and application of component parts are closely interrelated. The component part engineer should have a knowledge of circuitry and expected environment as well as detailed part characteristics. To ensure the selection of the best parts and their proper application, work must be planned in the following areas:

    a. The preparation of preferred component part lists based on laboratory tests and field experience with production systems.

    b. The preparation of specifications establishing the environmental and characteristic limitations on the preferred parts. The inclusion of failure rates with a demonstration plan is a necessity for high reliability long life systems.

    c. The establishment of a program to standardize on the minimum feasible number of different component part types.

The implementation of the recommendations of the "Ad Hoc Study Group on Parts Specification Management for Reliability" should materially improve the component part situation.

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                    ┌─────────────────────┐
                    │    RELIABILITY      │
                    │    ENGINEERING      │
                    └─────────────────────┘
        ┌───────────────────┬─────────────────┬──────────────────┐
┌─────────────────┐  ┌─────────────────┐  ┌──────────────────┐
│ Reliability     │  │ Field Evaluation│  │ Component Part   │
│ Analysis        │  │                 │  │ Engineering      │
└─────────────────┘  └─────────────────┘  └──────────────────┘
     ┌────────────────────┐    ┌────────────────────┐
     │ Environmental Test │    │ System Evaluation  │
     └────────────────────┘    └────────────────────┘
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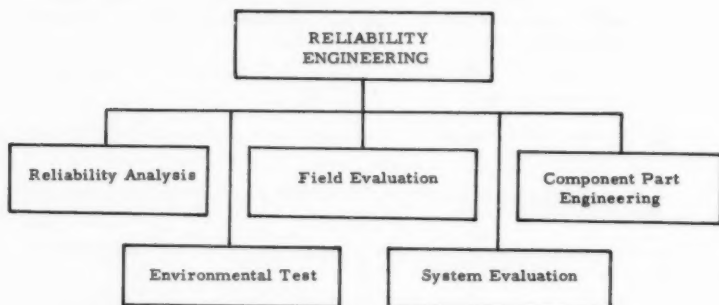
<div align="center">Figure 3</div>

System Evaluation serves as an unbiased group evaluating the reliability, maintainability, operational suitability and specification performance of prototype systems. System Evaluation must plan the bench test program so as to get significant, statistically sound measurements of the previously mentioned system characteristics. The questioning attitude as a method of control must be encouraged if all malfunctions are to be treated as foreshadowing future trouble in field usage. This is necessary to overcome the natural optimism which tends to view a failure as the random one in a billion occurrence that will never happen again. At this stage any marginal aspects of the design must receive careful consideration. The maintenance of running distribution plots on critical circuit and system measurements can be very helpful in uncovering either loose or unrealizable tolerances before production starts. It is of extreme importance that the fixes for malfunctions are not of a marginal nature such as tube selection, matching of component characteristics and setting of unrealistic reduced machining tolerances. These can appear as attractive fixes when testing equipment produced in a model shop, but usually become disastrous when released to production. It is essential that System Evaluation have the attitude "Anything that happens here is sure to happen in the field."

Environmental Test can very profitably have all the plant's environmental facilities and provide testing services to all areas. Environmental Test performs all environmental tests on component parts, assemblies, units and systems. For military systems the test conditions are those listed in military specifications modified by expected system usage. The importance of testing commercial systems in the environmental conditions expected in the field often gets too little attention. Life testing of component parts, units, and systems under realistic usage conditions is an additional function of Environmental Test. The importance of environmental and life tests to reliability has had much stress in the literature. This importance, coupled with the obvious large expenditures involved, makes test planning mandatory. Test to failure and accelerated life testing have received much attention recently. A program jointly planned by Reliability Analysis, Component Part Engineering, Environmental Test, and System Evaluation is needed. Large savings with a possible increase in useful data is possible from a careful combining of life and environmental testing. Specific work in the area of correlation of test to failure and accelerated life test results with normal laboratory and field experience is needed. The development of analytical expressions relating failure rates with test conditions should be the long range objectives of such a test and analysis program.

Dependent on the nature of the product a Field Evaluation group may or may not be necessary. The developers of manned airborne systems and automatic chemical process control systems as examples have field evaluation groups called Flight Evaluation and Pilot Plant Evaluation. The objective of groups such as this should be the evaluation of reliability, maintainability, operational suitability and specified per-

formance under controlled conditions approaching those expected when used by the customer. In order to attain the objective, efforts must be planned in the following areas:

    a.   Specification preparation.

    b.   Test instrumentation.

    c.   Data collection, reduction and analysis.

    d.   Operation and maintenance of facilities.

Attainment of specification performance reliability, maintainability and operational suitability in the Field Evaluation situation is normally the signal for production to commence.

Quality Control must plan a program to assure that the product reliability shown in Figure 2 approaches the design reliability. Figure 4 shows a suggested organization of Quality Control into three areas, namely, Inspection, Quality Engineering, and functional Test and Metrology.
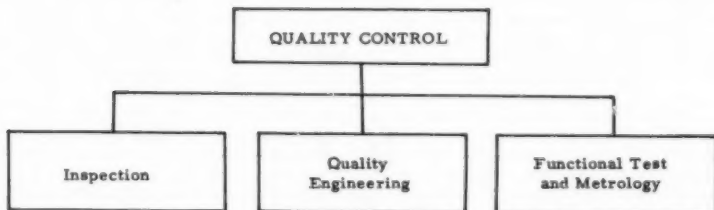

Figure 4

Inspection has the responsibility of assuring that parts, processes and purchased items agree with the specifications. This area provides the basic measurement data which is used for determining the quality and reliability of the parts, processes and manufacturing techniques. The importance of inspection is well recognized and the methods and procedures utilized have been well documented in the litarature. Consideration should be given to introducing the vital reliability factor of time into the inspection program. This could be done by instituting periodic life tests on parts and processes to determine the time variation of characteristics, degradations, and catastrophic failures. The feasibility and economy of lot qualification by complete life and environmental testing of a sample merits study as a measure to assure the continued quality and reliability of a vendor initially qualified during system development.

Functional Test and Metrology has the responsibility for the testing of assemblies, units, and systems as well as the maintenance and calibration of all test equipment and measurement standards. Since most reliability definitions include specified or satisfactory performances as a criteria of a reliable system, the accuracy and range of the measuring equipment is of extreme importance to quality and reliability. The planning of the required accuracy of electrical and mechanical standards and working test equipment should cover the complete product cycle including research, development and production. Planned maintenance and calibration checks

are needed to assure constant and known errors of all measurement equipment. Research in the elimination or compensation for unknown parameters affecting measurements contributes to the dependability of the measurements.

The static and dynamic testing of assemblies, units and systems for compliance with specifications is a conventional quality measure. Life testing in these areas on a sample basis is a definite reliability measure in production. Such tests must be for more than the determination of failure rates and satisfaction of reliability specifications. It is most essential that all malfunctions be analyzed for cause and that corrective action be taken on all systematic malfunctions. Production system reliability testing requires careful planning in the following areas:

a. Duration of test.
b. Failure reporting and analysis.
c. Definition of failure.
d. Rejection criteria.
e. Environmental and operational conditions.
f. Programmed operational cycle.
g. Maintenance program.

Quality Engineering has the responsibility for the planning and implementation of methods of prevention, analysis and corrective action in the areas of quality and reliability within the manufacturing process. Emphasis on the preventive aspects of reliability in manufacturing is a must if high quality and reliability are to be realized at a reasonable cost. Experience in a number of organizations has shown that increased preventive efforts have resulted in reduced inspection costs (without a reduction of detection functions) and a net saving in the total quality expenditures.

The placement of key Quality Engineering personnel in certain Reliability Engineering, Development Engineering and Purchasing areas before the new product is released for production is an excellent method of taking preventive reliability action. The key Quality Engineers in these areas can detect unrealistic tolerances; critical part, unit and system characteristics; undesirable vendors and impractical measurement requirements at an early date. As a consequence, preventive action can be taken in development rather than in production. Providing the inspection and test areas with complete procedures, instructions, techniques and statistical services is an important preventive action. Research in the statistical areas of sampling, design of experiments, correlation, and analysis of variance are needed to bring the essential time characteristic of reliability under better control and measure in the manufacturing process.

In order to obtain the data needed for analysis and corrective action, specifications and forms for the control of materials, processes, parts and systems must be provided. A statistical analysis system for failures in processes, parts, units and systems must be set up to cover production. Cordination with maintenance and repair depots is essential for the analysis of malfunctions and assessment of responsibility to workmanship, poor design, misapplication of parts, unsatisfactory parts and misuse. With the increasing tendency of the prime contractor to purchase a large portion of all parts and to subcontract a substantial fraction of assemblies, units and subsystems; the maintenance of reliability and quality standards during production at vendors and subcontractors becomes extremely important.

Quality Engineering should survey prospective vendors and subcontractors for their quality procedures, test facilities, reliability programs, and production capabilities in conjunction with Engineering and Purchasing. After rating and initial selection, Quality Control must evaluate vendors and subcontractors on the basis of the product delivered. Feedback of discrepancy and failure data to the vendor is a necessary step in the corrective process. Consideration should be given to having qualified and reputable vendors conduct type tests and periodic requalification tests as this can result in earlier and more effective corrective action in addition to providing test information needed by the prime contractor.

Having responsibilities in the production process for specifications, data analysis, vendor survey and vendor evaluation, Quality Engineering is in an excellent position to be responsible for seeing that corrective action is taken. Coordination with the various areas that have to take the necessary corrective action is, of course, of great importance. Keeping top management informed by scheduled status reports on the corrective action program is than a Quality Engineering task.

Areas of mutual interest to Reliability Engineering and Quality Control include failure reporting, failure analysis and multiple source development on component parts and subcontracted items. A reliability and quality program must have a failure reporting system if continuity is to be maintained from project to project and if past experience is to be most effectively utilized. Failure data is generated on all levels from the component part to the system and in all phases from research through development, production, and useful operating life with the customer. It is obvious that the primary objective of Reliability Engineering is assurance that reliability is inherent to the design released for production. The primary objective of Quality Control is assurance that reliability and quality has been built into the production systems. Since failure reports properly obtained and analyzed can yield component part and circuit failure rates as well as data for evaluating and refining prediction techniques, it appears that Reliability Analysis should operate the failure reporting system starting with factory acceptance and continuing to obsolesence in the field. In the area of in-process failures in inspection, assembly and test, the interest of Quality Control is paramount, so Quality Engineering should handle the failure reporting and analysis in these areas. Experience has shown that the assignment of people to the field at sample locations with the sole responsibility for reporting failures and reliability conditions greatly improved the accuracy and completeness of the reports. If reliability predictions is ever to become reliability calculation, controlled field reporting and reliability measurements are essential requirements.

During development it is often difficult to justify the development of second or multiple sources for component parts and subcontracted items. This often results in qualifying additional sources late in the development phase and during the production phase. The question of the location of responsibility and authority for development and qualification can be a serious one. All too often control is divided or transferred during the program. It is felt that this work can be done in Production Engineering, Quality Control or Reliability Engineering. In general, each of these areas has sound reasons both for doing and not doing this work. Management must weigh the pros and cons and decide each case on merit, assigning the complete task with responsibility and authority from initiation to completion.

The direction of a reliability program varies from the direction of other engineering and manufacturing efforts only in degree. While it may be trite to say that reliability is everybody's business, the cooperation of everybody is needed if the reliability objective is to be attained. Cooperation on reliability is best obtained when the parties involved understand and appreciate the importance of the subject. Hence, an active education program requires constant and active direction on the part of the Reliability and Quality Division Manager. The use of the following media have proved of value in reliability education:

     a. Manager training program.
     b. On the job training.
     c. Engineering seminars.
     d. Attendance at conferences and symposiums.
     e. Posters and company newspapers.

The scheduling of reliability tasks is of extreme importance and requires detail direction. As an example, life and environmental testing at the component part, circuit, and unit level must be completed at an early date if test results are to be used to refine the reliability predictions. Availability of test data revealing unsatisfactory component parts and design at a sufficiently early date permits corrective action or parallel developments so as to prevent more serious difficulties in produc-

tion. A careful balancing of available test time and sample size (and hence economic considerations) must be made if scheduling is to have proper direction.

Coordination of the total reliability effort is a sensitive area as reliability and quality depend so heavily on design and manufacturing techniques. A Reliability and Quality division can most effectively get its recommendations accepted by selling and persuading the responsible areas based on the self-interests of the area. Establishing a record of competence and sound judgment in the various Quality and Reliability services does much to develop the confidence on which coordination is based. It must always be remembered that a Reliability and Quality division is essentially a service organization and that the responsibility and accountability for design reliability and product quality reside in Development Engineering and Manufacturing respectively.

Reliability Engineering has coordination problems among its several areas. As an example, Reliability Analysis, Component Part Engineering and Environmental Test must coordinate the life and environmental testing of component parts. Reliability Analysis is concerned with failure rates, degradation, statistical significance, and modes of failure. Component part Engineering is interested in establishing application limits and obtaining certification data. Environmental Test is concerned with instrumentation requirements, range of life and environmental test conditions, frequency of measurement, and automated testing. These requirements of the several areas are sometimes in conflict and coordination is needed to assure the greatest benefit to the reliability effort.

Reliability Engineering must coordinate with Development Engineering, Production Engineering, Quality Control and Research in the following areas:

     a. Scope of standardization effort.
     b. Selection and qualification of second sources.
     c. Form and content of failure data reports.
     d. Design methods for reliability.
     e. Requalification of vendors.
     f. Reliability efforts on research systems.

These are only a few examples from a lengthy list and are chosen only for illustrative purposes.

Reliability Engineering and Quality Control have coordination problems with the customer. Reliability Engineering needs field failure data which must be provided by the customer or collected on his premises. The natural desire of the manufacturer and customer with high stakes in equipment reliability to both collect data and analyze it in their own way requires a high management level of coordination to avoid duplication and ensure a reasonable agreement between reported results. Quality Control feels that first hand verification of field discrepancies is necessary for expedited corrective action. Hence, they desire representation on the customer premises rather than being dependent on second-hand information that is often difficult to confirm independently.

Having set up specifications and procedures to ensure in the house reliability and quality, coordination with vendors and subcontractors is a necessity. The differences in organizational structure, procedures and management philosophies present many problems. Many compromises are normally necessary to arrive at mutually satisfactory quality and reliability programs at vendors and subcontractor facilities. The advisability of reconciling differences and spelling out commitments in the contract negotiation and purchase order phases are obvious. For the manufacturer with prime responsibility for a system, careful attention and consideration in this area can eliminate a multitude of troubles.

Quality Control often has coordination problems with Production Engineering and Manufacturing. The assignment of priority for corrective action based on the correlation of in-process and field failures is such an item. The definition of re-

sponsibility for the three functions in the product improvement program requires continuous coordination. The determination and reporting on the effectiveness of changes in manufacturing techniques, inspection sampling, acceptance specifications, and design changes as these changes are broken into production are Quality Control functions that should improve coordination efforts.

The preventive nature of a Reliability and Quality program increases the critical nature of the control function for management. Only by establishing sensitive control measures can the necessary changes be made in the reliability effort before the design is committed to production. The use of time scheduling with frequent reports on the progress of the various reliability tasks is an excellent basis for reassigning manpower and facilities to assure compliance with the schedule. The use of control techniques such as PERT and PEP can be of great value in meeting the reliability schedule.

A major control for the technical evaluation of the Reliability Engineering effort is the setting of mean-time-to-failure goals for units, subsystems and systems on a time schedule corresponding to the planned reliability prediction, design and measurement check points in the program. At each measurement time, control may be exercised by modifying predictions and changing individual unit and/or subsystem mean-time-to-failure goals so as to realize the system reliability goal. If adjustment is not possible within the subsystem reliability apportionment, redesign action may have to be initiated or a product improvement program planned if schedules don't permit redesign.

Frequent and scheduled reports on the release of component parts, results of life and environmental tests of component parts, failure analyses on unit life tests and vendor quality evaluations provide excellent controls for a component part standardization program. Testing of additional component part types within a category may be cancelled as a result of a certification report or additional testing may be initiated as a result of discouraging test results. Careful utilization of these controls can assure the certification of reliable component parts before the system is released to production.

In summary, it can be stated that the quality and reliability effort must start with the first concept and continue through development, design, and production to ensure high reliability in operational systems. A Reliability and Quality division provides the continuity of services needed to assure attention to all details at the proper time in the program. The exercise of skill in the management functions of planning, organizing, directing, coordinating and controlling is necessary if the reliability and quality objectives are to be realized.

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TOTAL QUALITY CONTROL IN SMALLER INDUSTRIES

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INTRODUCTION

In his paper "The Challenge of Total Quality Control", Dr. A. V. Feigenbaum of the General Electric Company has described total quality control as the integration of quality control efforts from market research and engineering design through to shipment and final installation of the product such that the customer remains satisfied and the costs of maintaining that goal are at a minimum. He has pointed out that welding together the quality efforts of all the functions in a company pays off in lower quality costs and better interdepartmental relations than can be achieved in any other manner.

Dr. Feigenbaum has pointed out further that the cost of controlling the quality shipped and the cost of satisfying the customer can be minimized only if attention is paid to the prevention of defects. Increase in cost in this area will reduce the cost of appraising quality and replacing or repairing defective goods in the plant or at the customer's location.

It is true that the General Electric Company is a very large organization. There are many in small industries who will say that, "Yes this is worth while for large companies which have money to spend on elaborate control systems, but does it really have its place in small industries? Is the cost of setting up such a program really worth while? Will it pay off?" In this paper I propose to describe how this concept of total quality control can and has saved dollars for small companies and given management and employees a new concept of co-operation in achieving customer satisfaction with minimum interdepartmental conflict.

WHAT DOES THE CUSTOMER WANT

How do we go about achieving total quality control? First of all we must learn what our customer wants. Sometimes the only way to determine this is by studying complaints to learn what he does not want. If we are starting with a new product to be made to a set of specifications provided by our customer we are in a fortunate position. It enables us to sit down with our sales department and the customer and go over the specifications concentrating on those details which have raised any doubt in our mind as to his requirements and learning from him in particular what quality characteristics are of prime importance to him in the function of the product or its assembly into its final location. As Dr. Feigenbaum has indicated in his paper, a great deal of grief can be prevented if we make sure what is required to make our product function correctly after it has been received by our customer and installed. The sales organization is one of the keys to good communications with our customers.

OUTGOING QUALITY CONTROL

Once we are sure what is required, our next step is to make sure as well as we can how well the product conforms to the customer's requirements or our engineering design before it leaves our plant. Final inspection is supposed to achieve this purpose. However, experience has shown that if quality is not controlled during manufacture some defective products will reach our customer no matter how much inspection is applied just before the product leaves the plant. Final inspection can be extremely costly and yet not entirely reliable. Final inspection must be considered only as a reporting of quality achieved during design and manufacture in comparison with the requirements of our customers.

PROCESS QUALITY CONTROL

If 100% final inspection is not 100% effective while at the same time causing high cost in rejects, what can we do? In-process inspection will give us early warning of trouble and a chance to correct the process. This can be established in either of two ways.

The first is to establish inspection stations at various stages of manufacture, using various sampling plans and 100% inspection when necessary to catch defectives.

The second method is to set up patrol inspection in an effort to discover operations which are producing defectives before much product is manufactured. In either method there are two prime requisites. The first is that the operator is given whatever measuring equipment is necessary to enable him to measure the quality of his own operation. The second is that the results of any inspection from his finished product must be given to him immediately. Beyond this, foremen and supervisors must be kept aware of any tendency of operators to put off making necessary correction to produce a good product.

Defects must be prevented. The whole objective of patrol inspection or sampling inspection must be to measure the effectiveness of the control of quality by the operator and report to him or her and the supervisor what sort of quality performance is being achieved. Detailed information regarding the kind of defects can help the operator or supervisor decide what corrective action needs to be taken.

There are instances when the control of quality is somewhat out of the hands of the operators. Such a condition can arise when the material is off standard, or the equipment being used in the manufacturing process is not capable of producing within the specified tolerances, or the measuring equipment being used is not sufficiently accurate. Knowledge of quality of the material being used can be gained through proper sampling inspection as the material is received. Costs due to defective material can be avoided by the manufacturer if he knows of the condition of the material early enough to either get a replacement shipment from his supplier or make arrangements with the supplier to pay for extra operations required to produce a satisfactory product.

CAPABILITY FOR QUALITY

The capability of the equipment being used in the manufacturing process is one of the most important factors in the control of quality. Very few operators are skilled enough to produce to specification when the equipment he is trying to control has a natural variation which exceeds the tolerances allowed. I have seen a skilled operator produce within the specification limits while a study was being made of his operation but yet the product reaching the assembly line had a considerable percentage outside the specification limits. Therefore, it is worth while to have capability studies made of all equipment, particularly that which is producing defective product, in order to determine whether it will produce to specification or must be repaired or replaced.

The accuracy of the measuring equipment is again extremely important in the control of quality. It is unfair to ask an operator on a grinding machine to control parts to a total tolerance .0005 of an inch and provide him only with a snap gauge set to the upper and lower limits. First of all, in setting the snap gauge, the amount of pressure used by the inspector may be different than that used by the operator when he receives the gauge. If he is measuring a round piece with a gauge which has been set up with standard gauge blocks, it is unlikely that his measurements will correspond exactly with those gauge blocks. Second, he can only tell when the parts he is grinding are at the upper or lower limits; he cannot tell when he is approaching either limit and therefore cannot prevent parts from being made at or outside the limits. The alternative of course, is to provide him with a sensitive gauge which will measure the diameter exactly in increments of .0001 or better still .00005.

An important part of in-process control is gauge control. All gauges whether the property of the employee or the company should be inspected regularly for accuracy sufficient for their purposes.

INCOMING QUALITY CONTROL

Receiving inspection is necessary if final quality is to be controlled. Whether the material is to be used in our own manufacture, or consists of components which are packaged for resale, we must be sure that the quality meets the customer's requirements. Let us not make the mistake of assuming that because we did not make the material we are not responsible for it. Let us remember that the customer considers us completely responsible for all materials received from us. A well planned program of receiving inspection using statistical sampling plans will keep us informed of our vendors' quality.

Receiving inspection does not end with knowledge of quality or return of defective shipment to our vendors. If we are to control quality at the lowest cost we must work with our vendors to help them improve their quality. Let us remember that if a vendor is having trouble and has to inspect his product 100%, the cost of his own quality control will be passed along to us in the price of the goods. Therefore, it is impor-

tant that we keep him informed of the mistakes which he makes and whenever possible
teach him some simple quality control techniques which will help him control quality
during his manufacture, and insure us of good quality without costly sorting, rework
and replacement.

DESIGN QUALITY CONTROL

Up to this point we have considered quality control in the manufacturing process
under conditions where no consideration is given to altering specifications. This is
the usual attitude taken by the sub-contractor manufacturing for a customer who has
provided his own specification. The only time that a sub-contractor is likely to seek
a specification change is after he has found that he is unable to adhere to that spec-
ification. Interestingly enough this also happens in larger companies where good
liaison is not habitual between the manufacturing department and the engineering de-
partment.

In a program of total quality control close liaison between engineering, quality
control, production engineering, and manufacturing, is an essential ingredient for
success. Thus the manufacturer who is producing to customer specification is well
advised to pass on to his customer not only his problems in the control of quality due
to close tolerances but also the cases where he can control quality easily with closer
tolerances than specified. It could be very much to the advantage of the customer if
he can reduce the tolerances of that part and allow wider tolerances on another. Such
co-operation between you and your customer can only improve relations to the extent
that your company is preferred over others. Any savings which a vendor can pass on to
his customer not only reduces the cost of the customer's finished product but also
invites new business.

QUALITY OF SERVICE

Finally let us consider the service we give to our customer after the goods are
delivered. Let us be honest from the beginning and discuss with the customer the
possibility that some defective product will reach him in spite of our quality control.
While we will do our utmost to prevent the shipment of defectives something may happen
during manufacture which will produce a low percentage of defectives unknown to us.
It can happen particularly with short runs. Therefore let us enter into an agreement
with our customer regarding the acceptable quality level for our product, that is, the
percent defective which he can afford to accept at a given price level. If his use of
the sampling plans for that acceptable quality level results in a rejection of our pro-
duct we must be prepared to do whatever is necessary to sort the defectives out of the
lot and make any necessary replacements. It is at this stage that the importance of
control of quality during manufacture becomes most evident because only with it can
serious delays be minimized and relations with our customers kept sweet.

A CASE HISTORY

It has been my fortunate experience to work with a number of small manufacturers
who must practice total quality control in order to increase their business in the face
of the keen competitive conditions of today's markets. One of these, the Turnbull
Elevator Company Limited, Toronto, Ontario, is somewhat unique in that the product is
designed to the customer's special requirements, produced in the company's plant in
Toronto, and erected in buildings in every province of Canada. Their control over
quality extends from the design stage right through to the final installation and their
products are competing successfully with larger manufacturers.

The installation of quality control began almost a year and a half ago with a
study of defects originating in each department being made to find the most common type
of defects, the completeness of information provided in specifications, the adequacy of
tooling and gauges, and which products appeared to be causing the greatest difficulty
and highest costs. At the same time a meeting was held with construction supervisors
to encourage the flow of information from the erecting crews back to the factory re-
garding defective material and shortages reaching them. These reports gave us a means
of measuring the effectiveness of the control measures we were introducing.

Process Control

In this type of manufacture very few items are ordered in large quantities. There-
fore, attention was focused on the control of quality of each operation, and provision
of some incentive to each department to improve control of quality. This was achieved
through departmental percent defective charts, placed on display and plotted on a
weekly basis. As a result of operator interest and management action to correct the
conditions which were found to contribute towards defectives, the percent defective
showing on these charts declined in a very satisfactory manner.

It is interesting to note that an increase in inspection force was not necessary. An analysis of their duties revealed that they were performing extra duties belonging to other functions, and 100% inspection on some products. One such product was made in large quantities for use in the electrical controls. A study of the process for these parts resulted in the development of new toolage which improved it to the extent that sampling at regular intervals was sufficient to control the quality. In this case quality has been improved, production increased, and therefore, manufacturing costs reduced. In addition, inspectors now have more time to do the important job of measuring the quality being produced.

Design Control

Capability studies have been made on equipment that was producing defective product. Many tools, dies, and fixtures have been investigated when the parts did not agree with the specification. In many instances it was found that the difference between the finished part and the drawings were changed by the engineering department. In other cases changes in the drawings were requested to facilitate manufacture and assembly.

A major problem was the application of tolerances to old drawings. As in many industries of this size which have been in existence for many years, a large number of drawings in the files did not show any tolerances. Without tolerances it was difficult for an inspector to judge whether a part was acceptable or defective. The procedure we followed was to propose to the shop nominal tolerances for fractional and decimal dimensions for each type of operation. After receiving their agreement we submitted these tolerances to engineering. After a final settlement was reached, instructions were issued to the shop to work to these tolerances except where tolerances and fits were specified on the part drawing.

Gauge and Tool Control

In this plant as in many shops this size, much of the measuring equipment is owned by the operators themselves. Some of this equipment was found to be something less than perfect. As a result, a survey has been made of all the measuring equipment in the shop, listing its location and owner, and McBee Cards have been made up for each item. In future all equipment will be examined and checked on a regular basis, using the McBee Card File to designate what equipment is to be checked each week.

The control over punch press dies is very simple. Whenever an order is completed the last piece off the die is sent to the tool room with the die. The piece is checked for dimensions and finish with special attention to burrs, and the die reconditioned if necessary. No die is put back in storage without an OK tag from the tool room or an OK by the inspector.

Special Studies

Some special studies have been instituted on items where the cost of manufacture are high or the reliability is of extreme importance. These studies are directed towards finding what factors have the greatest affect on the quality of the article, either in the finished state or at each operation. The results of these studies will be a change in the method of manufacture to reduce the cost wherever possible and improve the reliability where necessary. One item in particular, a resistance panel, is made from an asbestos board which is very difficult to cut. Preliminary studies have indicated that another method of cutting will reduce scrap considerably below the present 18% without increasing the labor cost appreciably.

In another instance the component had to be adjusted after mounting. If it fails it can cause a serious loss of time and great inconvenience to the customer. Up to the present time the studies have resulted in improved toolage and improved quality on one part, and also an indication that an important factor in the operation of the component was being disturbed by the adjustment that was made after assembly.

In-Coming Quality Control

In the receiving department, sampling inspection is applied to all purchased components in accordance with their importance. The sampling plans have been designed to minimize the amount of inspection to give the necessary protection. Where trouble is found, suppliers are being instructed regarding the defects, and a start made in suggesting simple quality control procedures.

Shipping Quality Control

One of the complaints from the erectors in the field was a shortage of parts in the shipment. A study was made by sampling the shipments and the causes of the short-

ages traced to their sources. As a result the procedures relating to shipment of materials from stock and from the manufacturing floor have been revised. All those concerned have become very much more conscientious in making up the shipments.

Outgoing Quality
Because of the construction of elevators which must be shipped in the "knocked down" state, and in shipments which can be several weeks apart, the effort to control quality is concentrated in the design and manufacturing stages. The final inspectors are the erectors and the field adjuster who makes the final test on the completed installation.

Results
The result of all this work has been a marked reduction in the complaints from the field with regard to both quality and shortages. Some valuable changes have been made to reduce costs of manufacture. Each department in the company has become much more aware of its role in producing the quality which will satisfy the customer with less installation time, and less delay. In addition, there is a constant feed-back of information on manufacturing and design quality with continual improvements being made.

CONCLUSION

Nine basic principles will assure us of total quality control and a program of prevention which makes substantial savings for our company:

(1) There must be full knowledge of what the customer requires.
(2) The specifications must be clear and have realistic tolerances.
(3) The operators must have equipment which is capable of producing to these tolerances.
(4) The operators must have measuring equipment which can tell them when they are within specification and when they are not.
(5) Incoming materials must be inspected unless it is known that they are not likely to present a problem in our manufacture.
(6) We must maintain good relations with our vendors and help them establish their own control of quality.
(7) We should be ready to ask for and make changes which will improve the product for our customer and reduce its cost.
(8) We must carry on enough inspection on outgoing products to know that we are controlling quality satisfactorily.
(9) Our quality control department must be managed in such a way that it co-ordinates effectively the efforts of every one in the company towards producing good quality and satisfied customers.

A CHALLENGE TO LABOR AND MANAGEMENT

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Labor Unions have accomplished a great deal of good for the people of America. They have enabled the so-called "down-trodden" laborer to earn the highest of wages ever in the world's history. They have contributed no small amount to the comfortable living that is ours to enjoy today. They have been highly instrumental in improving the working conditions under which man has labored for many years. They have obtained for us social legislation that eases the minds of our citizens who are approaching the retirement age. Yes, organized labor has actually taken a very important part in affording the American people the highest standards of living in the entire world.

With these remarks as a sort of introduction, I do not wish to convey the idea that all these accomplishments are due solely to the efforts of organized labor; they have, however, been greatly instrumental in obtaining them for us. But, up to this moment, have we ever asked ourselves this question; What has been the cost? What is the price that we are paying for all these gains? Have we been blind in our hasty pursuit of the dollar and all that it will bring us? I will right now admit that I have far more hind-sight than I have fore-sight, but then haven't we all the same? Admitting this, let us then become introspective and self-examining. Above all else, let us be brave enough to admit our mistakes of the past and let us all have the "grit" and the "guts" to correct them, or at least let us see that we do not make the same mistakes again.

Industrial Management today finds itself in a very precarious position especially as related to the situation between organized labor and industry. We must remember that this relationship in general is set or determined by the so-called "big fellows"; the small businesses must follow or cease to exist. Again management must plead guilty in the situation in which we find ourselves because it has repeatedly yielded to labor in giving "an inch" only to find that in the end labor has taken the proverbial mile. Finally management wakes up to the fact that it has lost control of the plant and its operations.

The plant supervisors who, we all know, are on the scene at the very heart of the operations and who are familiar with all the details, will render their opinions in the early stages or steps of a grievance only to have the Industrial Relations department refuse to back them up and management yields to labor in order to save the bother of going to the next higher step in their grievance procedures. So it is in this manner that we of management give that inch only to lose the mile. In the last strike of labor against Big-Steel, did we not see that the industry wanted labor to grant a few concessions, only to be told where they could go. By stretching our imaginations merely a trifle, we could say that the industry wanted to get back some of the past "inches" that they had previously given away.

At the close of each strike when the generals of both parties involved sit down to bargain, to settle their differences and to write up a new labor contract, we hear that the concessions granted by industry will be more than made up by the increased productivity on the part of labor. But how many of us, to be honest with ourselves, have seen these promises materialize? I have seen plants in which both supervisors and their laborers will admit that they get 8 hours pay for 5 to 6 hours worked. What is the result? In this country, with its high taxes, so many of them deeply hidden but sorely felt, our native industry cannot compete under such conditions against foreign producers. In other words, we are losing our markets.

The members of the Metals Technical Committee of the A S Q C will recall that it was not so long ago that we heard that Japan was shipping steel rods into this country of far better quality and made to better tolerance limits at lower costs than we could possibly meet. Then, too, let us look at the compact-car situation. This market, long neglected by our native industry, was lost to us with its subsequent great steel tonnage. We can go on and on with similar illustrations. The big $64 question is, What are we going to do about it? It is high time that the three groups that should be vitally concerned about this situation should get together to think and talk this matter over. The three groups, of course, are Management, Labor and Government. These three must work more closely together than ever before in our history in order to hold our

present markets and in order to gain new ones. My friends, this situation, whether you realize it or not, is very serious; our future industrial welfare might well be dependent on what we do about it. My challenge to industry, labor and government, in this case is to forget your differences (if there are any) and strive for greater productivity and this productivity MUST be of better quality than ever before.

Unfortunately, quality of product in the past has been more or less haphazard in a great many of our industries. In several instances we have seen rejects or inferior products "slipped in" with good materials trusting to luck that they would not be caught. Inspection was considered and looked upon as a necessary evil and was always the first department to be cut back at the least provocation. If business dropped off to any great degree, that department was sure to be practically wiped out. And once cut back it was always most difficult to get the men back on the job.

Not so long ago (and even in our present day) it was considered good practice to take a certain fixed percentage of a lot in order to check its qualities and often a second sample would be taken if the results of the first were unfavorable. If the second test came up to specifications, the results of the first test would be promptly forgotten. With the advent of S. Q. C., industry hopped on the band-wagon because management believed that with this new tool, all their inspection troubles were over; it was a veritable panacea for their industrial ills; inspection costs would be sharply curtailed; no more reworks and scrap; etc., etc. In fact most of the plants had very little if any inspection costs.

I had the pleasure recently to be called by a small industrial establishment that has been engaged in the manufacture of textile machinery for three generations and were now having some serious complaints on quality of product. I was astonished to learn that all their employees were old men who had been in their employ for 25 to 50 years; they knew their jobs, the product, and were faithful and trusted employees. I was told that when the product left their hands, it was perfect. I requested permission to look over their past inspection records and I was very much surprised to learn that there were none. I can not say anything about the West, but this situation is quite common in the eastern part of our country and especially is it true relative to New England. Industry here seems to trust to luck and frequently they run into trouble. Consequently, when these industries board the S Q C band-wagon for a solution to their troubles, they are most impatient and want immediate results before they spend a cent.

I have seen many industries that sail along from day to day with 12 to 15 per cent scrap and never bat an eye lash; but, let it hit 25% for one day and the whole management staff runs amuck. You and I know that with 12% fraction defective that we will hit 25% on some occasions. If that same energy on the part of management were exerted on the 12 to 15 per cent to bring it down to some lower level, say 5%, a great deal of money could be saved. I have in mind an industry of this type. This concern has been in business for over 100 years manufacturing, in the last 25 years, a product that has been in steady demand in large quantities with the government as the prime customer. With the signing of a new labor contract, they suddenly realized, after six month's study, that they could not meet competitive prices. They hired a good quality control engineer and assured him that he would have full backing as the situation was desperate.

The engineer spent one whole week just getting acquainted with the men, the machines, the materials and the processes used. The following week, he inquired about past inspection records and was surprised at the voluminous amounts of historical data that was available in files, desk drawers, and even packed on the shelves in the so-called process control office. None of this data was filed in any chronological order, but was simply tucked away by the inspector at the end of his shift. After a few days of digging, the results of the last two month's production were taken just to see what the history was.

In Figure 1 we have the result as shown by a simple frequency distribution which covered the two shifts of operation. Figures 2 and 3 show the same data, but here we see the separation of the two shifts. Nowhere on the data sheets could any reference be found in regard to the specifications. All of the measurements were made to the nearest ten-thousandths of an inch. Quality Reports were then filled out as is indicated in Figures 4, 5, and 6 showing respectively that, if the processes were operating in control, the per cent of product beyond specifications would be approximately 42%, 21% and 73%. Up to this point, the engineer's task had been fairly easy. His next task is to have his first session with top brass. Here again he was amazed to learn that top management had been aware for some time of the large number of reworks

```
0.1346  1
 .1347  11
 .1348
 .1349  1
 .1350  1111
 .1351  1111
 .1352  1111
 .1353  1111
 .1354  1111  1111
 .1355  1111
 .1356  111
 .1357  1111
 .1358  1111
 .1359  1111  111
 .1360  1111  1111
 .1361  1111  1111  111
 .1362  1111  1111  111
 .1363  1111  1111  1111  1111
 .1364  1111  1111  111
 .1365  1111  1111
 .1366  1111  1111  1111  1111
 .1367  1111  1111  1111  1111  1111  1111  111
 .1368  1111  1111  1111  1111  1111  111
 .1369  1111  1111  1111  1
 .1370  1111  1111  1111  1111  1111  111
 .1371  1111  1111  1111  1111  11
 .1372  1111  1111  1111  1111  1111  111
 .1373  1111  1111  1111  111
 .1374  1111  1111  1111
 .1375  1111  1111
 .1376  1111  1111  1
 .1377  1111  1111  1111
 .1378  1111
 .1379  1
 .1380  1111  1
 .1381  1
 .1382  1
 .1383  11
 .1384
 .1385
 .1386  1
```

FIGURE 1 - - Frequency Distribution -- Combined Data

and reprocess material or pieces going through daily, but now the answer was "Now we've got to do something about this".

Acting on the advice of the engineer, the union grievance man was called into the session and the entire situation was explained step by step with the request from management that the union get in back of the quality control program as proposed in order to wipe out the high amount of reworks so that the competitive price could be met without the cutting of wages or the loss of the business. Here it was extremely fortunate that the grievance man was one of those rare individuals who had a good head on his shoulders with both feet on the ground.

The remedy suggested by the engineer was as follows:

1. An educational program for the supervisors and the operators involved.

2. The institution of a sampling plan and the careful measuring of the product by the operator who would plot the point on the chart.

3. A follow-up by the quality control observer or inspector.

```
0.1346   1
 .1347   11
 .1348
 .1349   1
 .1350   1111
 .1351   1111
 .1352   1111
 .1353   1111
 .1354   1111  1111
 .1355   1111
 .1356   111
 .1357   1111
 .1358   1111                              1
 .1359   1111 111
 .1360   1111 11                           11
 .1361   1111 1111 11                      1
 .1362   1111 111                          111
 .1363   1111 1111 1111 11                 11
 .1364   1111 1111 1                        11
 .1365   1111                              11
 .1366   1111 1111 1111 1111               1111
 .1367   1111 1111 1111 11                 1111 1111 1111 1
 .1368   1111 1111 1111 11                 1111 1111 1
 .1369   1111 111                          1111 111
 .1370   1111 1111                         1111 1111 1111 111
 .1371   1111                              1111 1111 111
 .1372   11                                1111 1111 1111 1111 1111 1
 .1373   1                                 1111 1111 1111 11
 .1374   11                                1111 1111 111
 .1375                                     1111 1111
 .1376   11                                1111 1111
 .1377                                     1111 1111 1111
 .1378   1                                 1111
 .1379                                     1
 .1380                                     1111 1
 .1381                                     1
 .1382                                     1
 .1383                                     11
 .1384
 .1385
 .1386                                     1
```

FIGURE 2 — 7 - 3 Shift   FIGURE 3 -- 3 - 11 Shift

Let us now look at the Figure 7 for the results achieved after the adoption of the suggestions. Everybody from the manager down was very well satisfied with the outcome. After a month or two under the sampling plan, management decided to discontinue this inspection station now that the process had settled down only to learn the hard way that it was necessary to go back to interval policing. Human nature being what it is, men will tend to get careless when not under surveillance.

New England industry is very slow to grasp the full possibilities of this new tool. I sometimes wonder if we as potential salesmen of quality control are not doing too much to publicize the n-th degrees of the science such as Operations Research, Reliability, Quality Assurance, etc. How fine shall we cut this piece of steak? Please do not misunderstand me. Each of these ramifications has its place in the highly technical field of modern industry, but why do we not get our fundamental processes under a state of satisfactory control first. We can, you know, be penny wise and pound foolish.

May I summarize that which I have tried to say up to this point. American industry and the American people face a very serious situation that threatens our economical

life. Industry must adopt a hard and fast policy with labor and must have a strong man
at the head of its Industrial Relations department. Do not give in at the very first
step of a grievance on the theory that it is better to give "this inch" in order to
save the bother and the expense of going to the higher steps. As I said earlier, you
give this inch and you will lose the mile. Sometime, somewhere, somebody, be it in
Labor, Industry, or Government must be big enough to say a "STOP" to this ever-increas-
ing spiralling of wages permitting foreign industry to come in and take away our
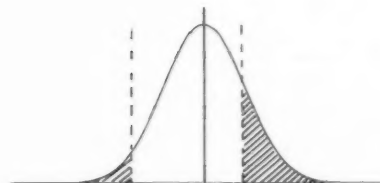markets.

Second; Management and Labor must cooperate on the installation of and the main-
tenance of quality control. Labor must realize that quality control decisions are
based upon fact and not upon guesswork. We are in the position today of attempting to
compete with foreign industry possessing the most modern equipment and the latest tech-
niques with the lowest of wages.

Finally: It is my confirmed opinion that it is of the utmost importance to get our
fundamental processes in a state of satisfactory statistical control and then MAINTAIN
that control through police action before we begin to further confuse management with
the deeper and more highly technical aspects of this science.
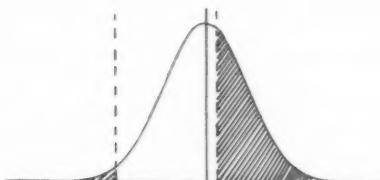
Below	Percent Above Specifications	Within
1.10	40.52	58.38

FIGURE 4 --Combined Data

	Percent Above Specifications	
3.14	17.62	79.24

FIGURE 5 --7 to 3 Shift

Below	Percent Above Specifications	Within
0.00	72.91	27.09

FIGURE 6 —-3 to 11 Shift

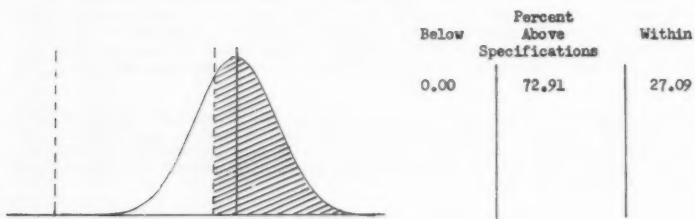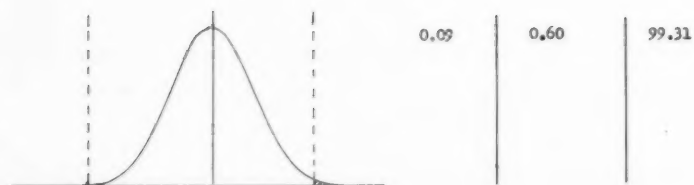| 0.09	0.60	99.31

FIGURE 7 --First Run After

BREADTH OR DEPTH?

Training for Quality Control and Operations Research

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It is surprising to many quality control people when such a subject as training for quality control is broadened to include a discussion of training for operations research. However, as far back as 1951 it was recognized that quality control was not the only answer to industry's search for better ways to operate. In an intriguing article[3] it was noted that

> "The over-all problem confronting industrial management from the inception of a product to its completed manufacture and distribution is the problem of Industrial Operations Research."

Littauer goes on to state later in the article that . . .

> "In problems of operations research, whether civilian or military, statistical quality control in its most general sense as the means for analysis of causes is indispensable."

This statement would seem to imply that statistical quality control is a part of operations research. Unquestionably this philosophy is not universally accepted.

As early as 1953[2] it was suggested that perhaps operations research was only the application of statistics and common sense to problems of business. Or possibly it was just a comprehensive term for existing activities such as market research, quality control, or industrial engineering. Here again a tie between QC and OR is noted.

Two years later the relationship of operations research to quality control and vice versa was somewhat clarified in two articles by Dr. Paul Olmstead[4][5], presently ASQC Chairman of the Operations Research Committee. However, in a panel discussion on "Operations Research in Quality Control and Quality Control in Operations Research" before the Washington Section in March 1960, it was evident to the audience and participants alike that it was still not clear where the two disciplines differed and where they were similar.

This paper will not attempt to settle any of the possibly conflicting viewpoints on OR and QC. Rather, the theme will be to discuss the training problems of these two fields and to point out similarities and differences.

WHY TRAIN?

The basic philosophy on training held by this author and many others is best stated in the following extract from reference[3]:

> "The continuing development of any intellectual discipline, however, cannot be guaranteed without the education and training of a steady stream of persons prepared to carry on and extend its traditions."

This paper assumes that training is vital and that the development of sound training programs will continue to receive the attention of those in industry, government, and the universities.

FORMAL TRAINING

There should be no question in the minds of those in quality control or operations research which of these two disciplines has progressed further in its development of formal training programs. The Operations Research Society of America commenced its Journal in 1953. The American Society for Quality Control started Industrial Quality Control in 1944. Although ORSA began publicizing its research nine years after IQC appeared, the college programs leading to degrees in Operations Research far outnumber those available in Quality Control. Does this relationship hold in the same way that one is more likely to find a program leading to a degree in American History, rather than a degree in History of the War of 1812?

As a statistician, I am unwilling to accept the thesis that quality control is necessarily a part of operations research. At the same time I cannot state that operations research is a part of quality control. Why then does operations research seem to be leading the way in formal training? One reason is undoubtedly the dramatic success OR practitioners have had in introducing these techniques in military and industrial problem areas. The pay-off for good quality control procedures is equally imposing. However, these pay-offs have frequently not been recognized as the result of applications of quality control methods.

A further point here is that OR tends to deal with total models while QC has unfortunately often restricted itself to minor parts of the operations of an industrial plant. It is these points plus a more aggressive group of scientists which have caused greater numbers of our young talent to seek formal training in operations research than in quality control.

The tendency in university training for OR is to prepare a man to handle a broad spectrum of classical problems in such areas as queueing, model building, linear programming, game theory, etc. The result of such curricula is usually a man with a broad amount of knowledge in most present day fields of application for OR. Unfortunately, however, OR is rarely discussed without mentioning the "team effort" or the "team approach." This implies a group of men working together on a specific problem. And, what of this group of men? Are they broadly trained, or are they specialists? Has their training been in breadth or in depth?

PRACTICAL TRAINING

An examination of efforts in OR, and also in QC, strongly indicates that the greatest success has been noted where the team effort was composed of capable and communicative scientists who were well trained in their own fields of specialization. A good OR team might consist of a physicist, a biologist, and a psychologist; or of a meteorologist and a mathematician. It is evident from the QC literature that the team approach is gaining considerable favor. In[6] it is suggested that a QC team might be composed of a shop supervisor, a product engineer, and a QC engineer. "Each member brings to the group his specialized knowledge." In another field[1] the QC team consisted of a research chemist, a technical service engineer, and a quality control engineer. Here, too, it was found that the interdisciplinary approach proved most successful. The inferences which may be drawn from the above situations are many. Most significant is the fact that many of the problems which were solved could never have been solved by a single man, either broadly trained or an outstanding specialist in one field. The requirements seem to be[7]

1. To have specialists who have mastered their own fields well enough that they can work in new situations;

2. To have men with above average ingenuity, creativity, and initiative; and,

3. To have a good interchange of ideas and communication within the group.

And how have these requirements been met in recent years? Not through most formal training programs! Instead, the unusually talented have been selected to become part of an OR or a QC team. The problem and the approach may differ but the basic ingredients are the same: the specialists working as a team.

ELEMENTS IN TRAINING

While the cries of agreement may not be loud, it seems that there are certain important elements necessary for the development of men who can serve as members of a team whether it be in OR or in QC. The elements are essential, in my opinion, to a good training program. These are:

1. To obtain a sound training in a specific area of specialization.

2. To maintain a close contact with reality so that obstacles and practical courses of action are clear.

3. To develop enough flexibility so that stereotype approaches are not used for all problem situations.

4. To acquire an ability to communicate the specific subject area to others in an understandable way.

5. To create a technique for conveying team and individual findings or conclusions in a clear and concise manner.

These five points do not tell how to achieve the training requirements. They only point out what should be a goal in training for OR and QC team members. The specific training program must remain a function of the aims of the firm or the academic beliefs of the university.

One final point, with respect to the importance of the individual trained in depth, is of significance. We must all remember that it is not enough to train others in the five areas indicated above. Those who make use of QC and OR teams must also be able to communicate their needs, identify and define their problems, and to interpret the findings. It would be unfortunate indeed if the users of QC and OR teams were to fall into the same pattern of thinking many Americans have regarding foreign languages: let them learn our language!

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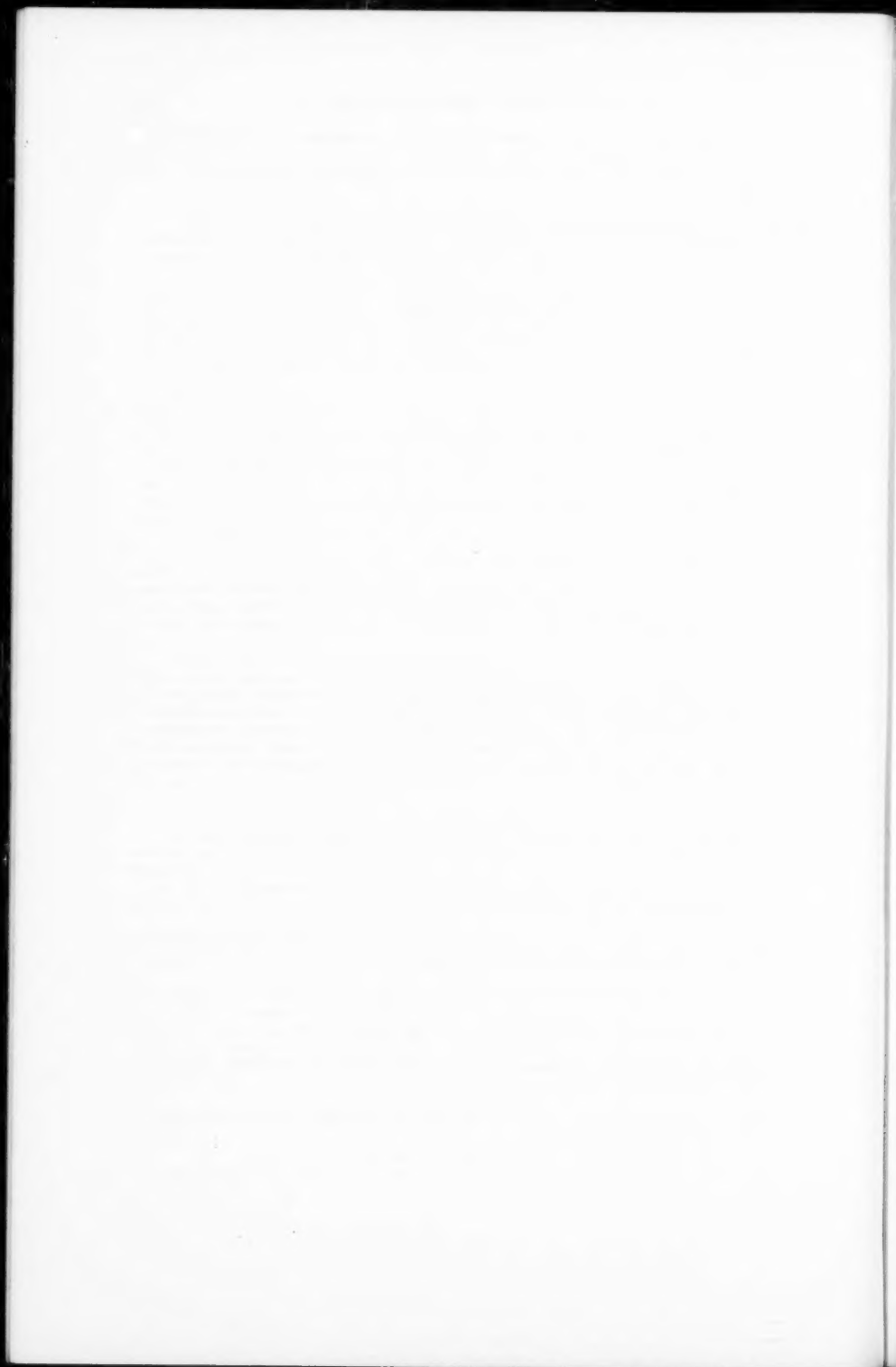
OPERATIONS RESEARCH IN MANAGEMENT

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The operations research approach has undergone a significant change during the past five years. For many years operations researchers have been occupied in describing the various aspects of the organization under study. They have often appeared to be preoccupied with the improvement and sophistication of their understanding of the phenomenon of business and less concerned with systematic implementation or application of their research results.

However, in the last 3-4 years many operations research activities have been directed to the study, improvement and "design" of systems of information--both planning and control in objective--by which management may discharge its responsibility. This paper is directed to a discussion of one such operations research study which has resulted in the design and wide use of a management information system used to plan and control large-scale R&D programs.

The PERT information system, designed to provide progress information to the management team of the Navy Polaris program is a significant example of what modern industrial engineering, working in conjunction with operations research and computer specialists, can achieve. PERT, which stands for Program Evaluation and Review Technique, was created by a "system design" approach quite similar in its scope and orderly development to the approach taken in the development of hardware items. It is the purpose of this discussion to describe the basic PERT system, its current extensions into the Cost and Reliability areas, and to touch briefly on some industrial applications being made.

PERT was designed to deal with the measurement and control of Time, ie., compliance to plans, scheduling, planning and prediction of progress. Other management research in this area, by the Navy, the Air Force and industry, is extending the PERT concept into measurement and prediction of Cost and Performance--where performance refers to the performance of the item under development.

Admiral Raborn, Director of Special Projects Office which has managed the Polaris program, often tells his people that "If you can think out a plan, you can also write it down". This message supports the planners to encourage their technical staffs to reduce to writing the ideas they have in their minds. This is a necessary first step in "creating on schedule". Lt. General Schriever, Commander of the Air Force Research and Development Command which develops the many weapons systems of the Air Force, has stated that one of their most serious problems in space and missile development lies in the development of management methods themselves. These two men, encharged with a large portion of our creative R&D, have thus laid down a challenge to all of us who are working in the management systems area, to develop management systems which can keep up with the technology that we are rapidly acquiring in the development of missiles and space vehicles themselves. Both men endorse PERT, the subject at hand, as a tool necessary in the reduction of both time and cost in our defense effort.

It has been the concept of "concurrency", i.e., concurrent design and development in order to reduce development time, that has created the need for a new technique, predictive in nature and able to cope with concurrent, interrelated activities thus created. The increased coordination and attendant information required are shown in Figure 1, which illustrates the added number of interactions required to operate in a concurrent fashion.

Admiral Raborn, in setting up PERT, has recognized the need for a significant effort to develop the management tools that go along with the creative technical work
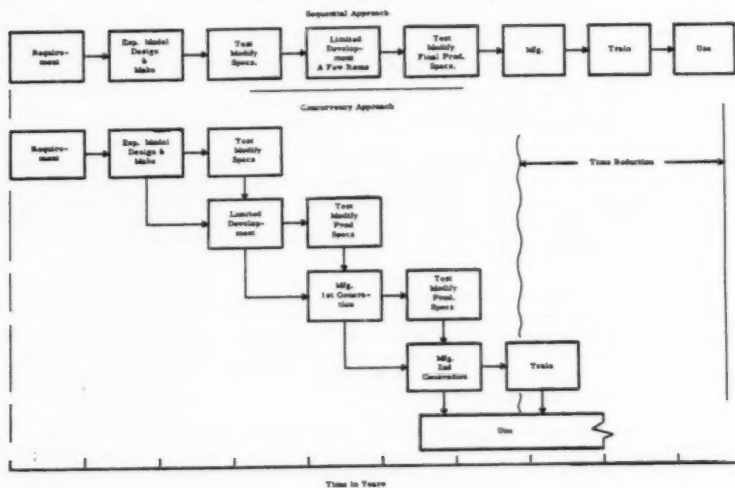
FIGURE 1 -- Shortening The Time for W. S. Development

that is involved. Recognition of this problem and putting research time and effort against it is a rather unique contribution in and of itself, for it generally is quite difficult to establish research projects in the operational management area.

Since initial application in Polaris, the concept has spread through several Air Force, Navy and Army programs and is being used in private industry for the management of the new product activity, where savings on the order of 20% have been claimed.

The Navy's program in PERT was part of a time-phased program much the same as we see in the development of a missile itself. We speak of generations of missiles, each one having greater range and other operational capabilities than the preceding generation. Likewise, in establishing management systems, the concept of going at it in a series of generations was conceived, and PERT represents the first such generation of a management information system. It tackles primarily the problem of Time compliance in a development program. Second and third generations of this management system are currently under development in the Navy: one in terms of Cost, dedicated to integrating cost or resource information with the time information; and another which is tackling the Performance, or reliability, measurement and control. In the latter area, it is hoped to provide a forward look at what the reliability problems are early enough to make the most useful tradeoffs and reallocation of resources.

A Description of the PERT Approach

In the PERT approach, the development program is first portrayed graphically as a network of interrelated activities necessary to achieve prescribed milestones, or events. Figure 2 shows a typical network or flow plan for a small portion of the Polaris program. Events are shown as squares in the diagram and activities as the connecting arrows. The "critical path" is the longest path through the given program. It is this part of the program that management is most vitally interested in determining, shortening and monitoring. The computer has been programmed to sort out from the many concurrent paths, which is the longest and next longest, etc. Figure 3 sums up some of the major definitions used in PERT.

TIME IN WEEKS
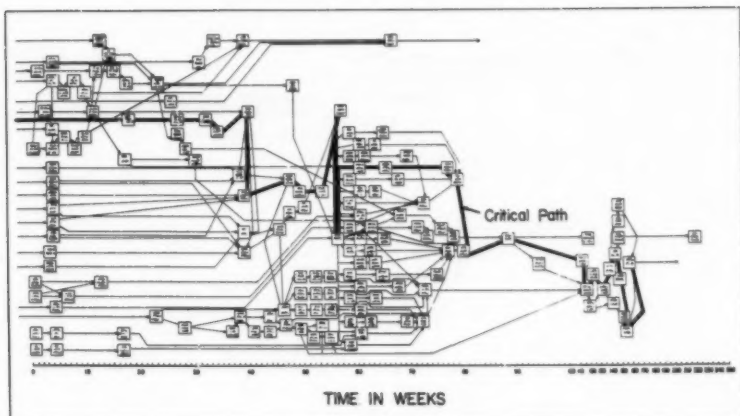
FIGURE 2 --PERT System Flow Plan or Network

EVENT

- AN INSTANTANEOUS OCCURRENCE WHOSE ACCOMPLISHMENT MUST BE KNOWN AT AN UNAMBIGUOUS POINT IN TIME.

ACTIVITY

- THE TIME-CONSUMING EFFORT, OR WORK NECESSARY TO PROCEED FROM ONE EVENT TO ANOTHER.

NETWORK

- A FLOW CHART MADE UP OF ONE OR MORE SERIES OF EVENTS JOINED BY ACTIVITY LINES TO DEPICT THEIR INTERDEPENDENCIES AND INTERRELATIONSHIPS.
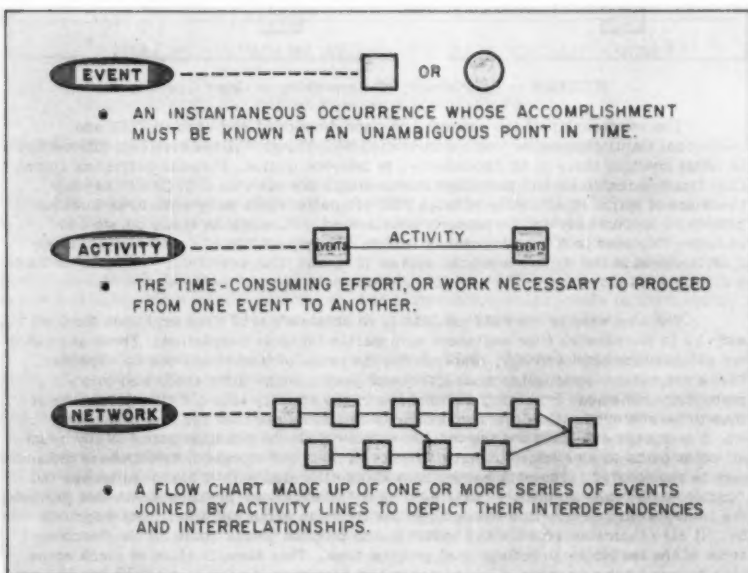
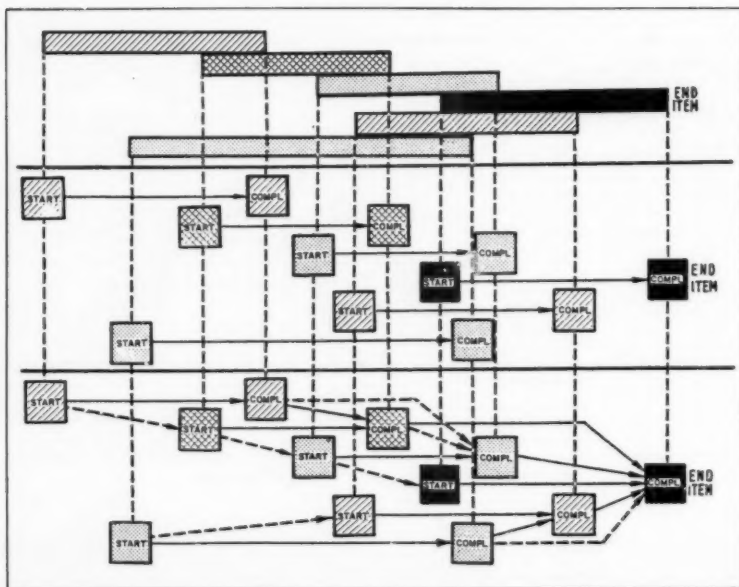FIGURE 3 -- Basic Definitions in PERT System

FIGURE 4 -- Relationship of Networking to Gantt Charting

The relationship of the network approach developed and used in PERT and traditional Gantt charting is worth commenting on. Figure 4 illustrates this difference. In Gantt charting there is no dependency, or interconnection, between activities shown. Coordination functions and precedent relationships are not shown in Gantt charting; these are of major significance in large R&D programs where many activities must be performed concurrently and be properly coordinated. Planning for these points and utilizing this plan in monitoring makes it more nearly possible to "create on schedule"-- a requirement in our current weapons system program. The use of the "network" is thus a significant innovation to the body of industrial engineering techniques.

The next step in the PERT process is to obtain elapsed time estimates for each activity in the network from engineers responsible for their completion. Three estimates are obtained for each activity, representing the range of time which can be expected. These estimates--optimistic, most likely and pessimistic--are transformed into a probability statement indicating the chances of the activity taking different lengths of time to be achieved. The flow plan and time estimates are then fed into a computer which computes and sorts out the longest path from all the possible paths to any event. All other paths to an event thus have "slack" in them and represent areas where resources may be reallocated. The path having zero slack allocated with it has been termed the "critical path" (see Figure 2). Thus PERT is a "Management-by-Exception" tool providing the manager with information where slips are likely to occur and what their magnitude may be. It also indicates where slack exists in the program and is guide for reallocating some of the resources to reduce total program time. This identification of slack areas also forewarns the manager of where not to buy attractive time reduction opportunities that may be preferred.

In Figure 5 typical data available to a manager are shown. Use of the three estimates makes it possible to develop a probability index for meeting or beating the schedule. The magnitude of this number may be used as a guide for determining the

EVENT NUMBER	EXPECTED TIMES		LATEST TIMES $(T_{OL} = T_{OE})$		SLACK $t' = T_L - T_E$	ORIGINAL SCHEDULE T_s^*	PROB. OF MEET'G SCHEDULE
	T_E^* EXPECTED	VARIANCE	T_L^* EXPECTED	VARIANCE			
50	92	38	92	0	0	82	.05
51	85	35	85	3	0	77	.09
54	74	29	82	4	8	73	.42
52	47	25	74	7	27	70	1.00-
53	70	31	70	7	0	60	.04
55	35	18	62	14	27	55	1.00-
56	60	26	60	12	0	50	.02
57	56	23	64	10	8	55	.42
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
X-NOW	0	0	•	•	•	•	•

*(TIME IS SHOWN IN WEEKS FROM X OR TIME "NOW")

FIGURE 5 -- Outputs from Analysis

relative seriousness of the potential schedule slip or for rescheduling.

In operation, PERT is maintained and updated according to a regular plan.
Figure 6 is such an operating description of PERT. Another feature of PERT is the possibility for "simulating" a change. The manager may introduce a synthetic time reduction and find out what would happen to the total program as a result. Often time-reducing changes do not buy equivalent time reduction in the program and may better be rejected. Many displays are possible from the data available in the PERT computer files. Figure 7 is illustrative of how critical paths at higher management levels in the program can be developed by aggregating the data. A variety of such reports are available.

Figure 8 assesses the role of the computer in PERT. It is highly important for management to specify what it wants out of the computer, and not have the computer lab tell management what it wants. It has happened often in the use of the PERT technique that the computer lab can see many possibilities of analyses and outputs of interest to them, which end up complicating the situation and making it difficult for management to see the real simplicity of the technique. The "management system design function" is one the industrial engineer fills--a sort of buffer between management and the computer lab. He knows the needs of management and is able also to communicate effectively with the computer specialists. The role of the system designer is becoming better recognized as the requirement for improved management controls is made.

Extensions of PERT

Up to this point we have discussed PERT. Let us now discuss some of the problems involved in extending management systems into second and third generations. In the PERT approach, only time estimates are obtained. It is possible for each one of the time estimates to obtain a cost estimate. Generally speaking, it is recognized that
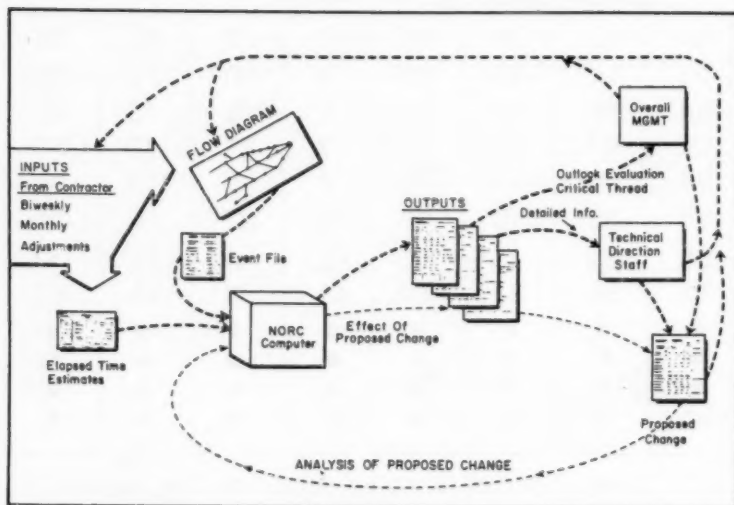
FIGURE 6 -- PERT System in Operation

at any given level of performance, if a reduction in the time of an activity is desired, it will take a disproportionate amount of resources applied to the task to get it done quicker. Further, if greater performance is desired at a given cost, it will take longer to achieve. Put in another way, for any given level of time, if greater performance is desired -- i.e., a better missile -- it will cost more and/or require more time. Figure 9 illustrates this relationship.

Early in the original PERT research, it was deemed impractical on two counts to cope with all three variables (Time, Cost and Performance) simultaneously in a computer model. First, related cost and time data on activities not experienced before are almost impossible to obtain with any degree of accuracy. It was almost impossible to get any-one to think significantly about such data. Further data on different degrees of the item's performance are even more difficult to obtain. Secondly, even if the data were obtainable, it would require a data processing load of about 20 times the data that the basic PERT system requires. Therefore, it was reasoned that if the total integrated Time, Cost and Performance approach was taken at the outset, the cost and data problem would defeat acceptance by the potential user of the system. It was decided to tackle the time variable first and then go after the cost variable after the information channels had been established.
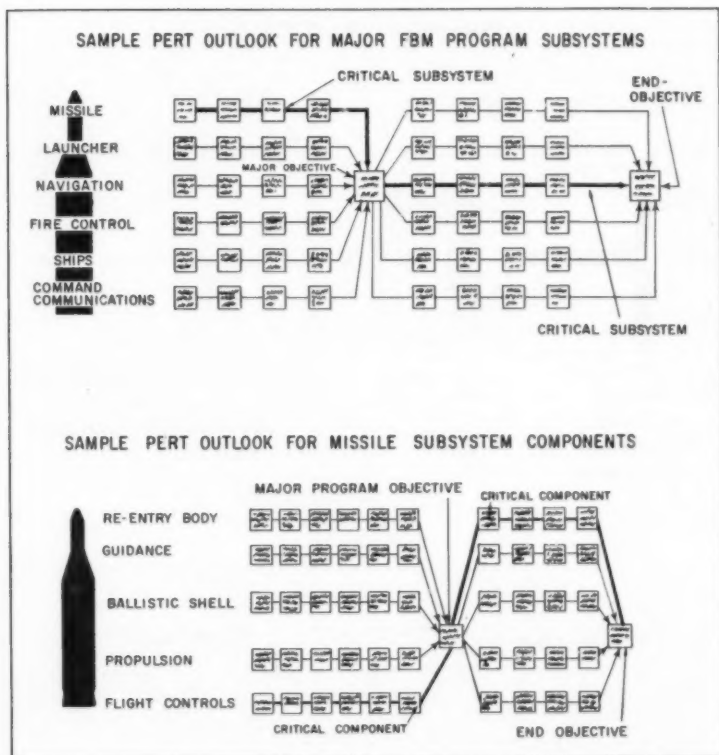
FIGURE 7 -- Integrated Outlook

A Principle in Management System Design

One major principle in management system design that was followed in PERT and its extensions bears stating. This is the principle of taking a vertical slice of the program for the study effort and pilot installation. Figure 10 represents a technical or hardware breakdown of the Polaris System. The various subsystems are shown across the top and are divided into components, etc. It was decided in PERT that one had to go right down to where the work was done, i.e., take a vertical cut, rather than taking the traditional horizontal cut in order to get immediate program results. In this way the ultimate system is completely consistent from top to bottom and one can have the

COMPUTER ROLE

PERIODIC TIME ESTIMATES
a - m - b

ACTIVITY CHANGES
◦ ADDITIONS
◦ DELETIONS
◦ COMPLETIONS
◦ RE-ESTIMATES

EXPECTED COMPLETION TIME
(T_E)

SLACK AND CRITICAL AREAS
$(T_L - T_E)$

PROBABILITY OF MEETING SCHED.
(P) AND
LATEST DATE FOR EACH EVENT
(T_L)

FIGURE 8

TIME, COST, PERFORMANCE RELATIONSHIP
FOR AN ACTIVITY

COST

P_1

P_2

P_3

TIME
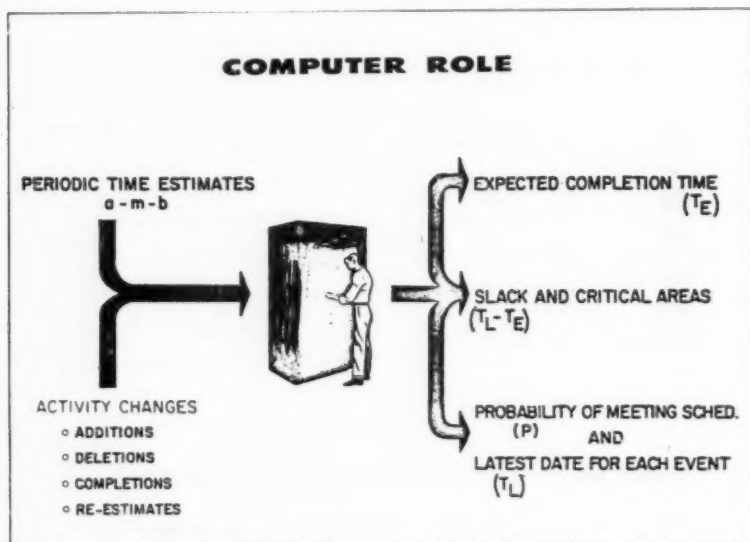
FIGURE 9

FIGURE 10 -- Vertical Slice of Development Program

FIGURE 11

confidence that data will be properly obtained and transmitted. After debugging this vertical slice, or pilot area, the system can be spread horizontally to other subsystems in a routine way.

Cost Extension

There are a number of ways costs can be assigned to activities. One, a range of possible costs could be applied to each activity; or, a single cost for each one of the time estimates in PERT could be made. Further, there is a choice concerning whether to use a single cost, direct costs, or total cost. As shown in Figure 11, PERT applications to date generally have applied direct man-hour costs, either in man-hours or dollars, to the activity, showing the department, code for the man, and in many cases identifying the individual man, where highly skilled individuals are a scarce commodity in great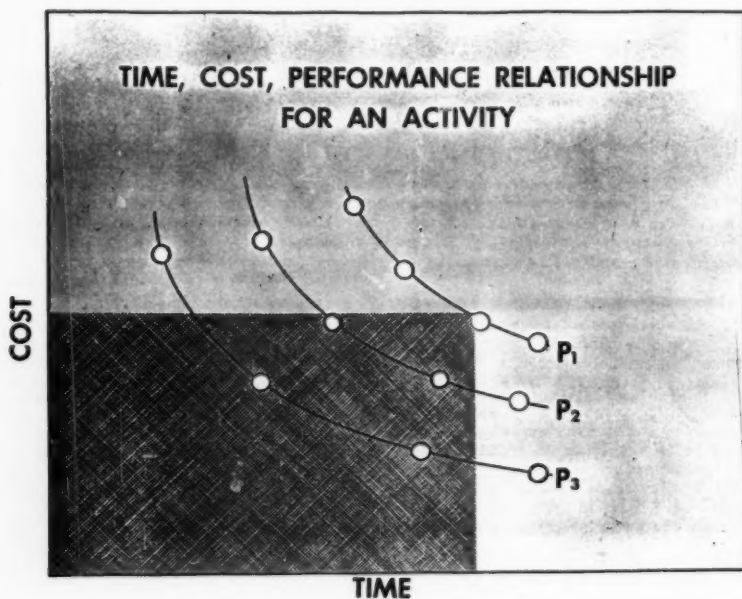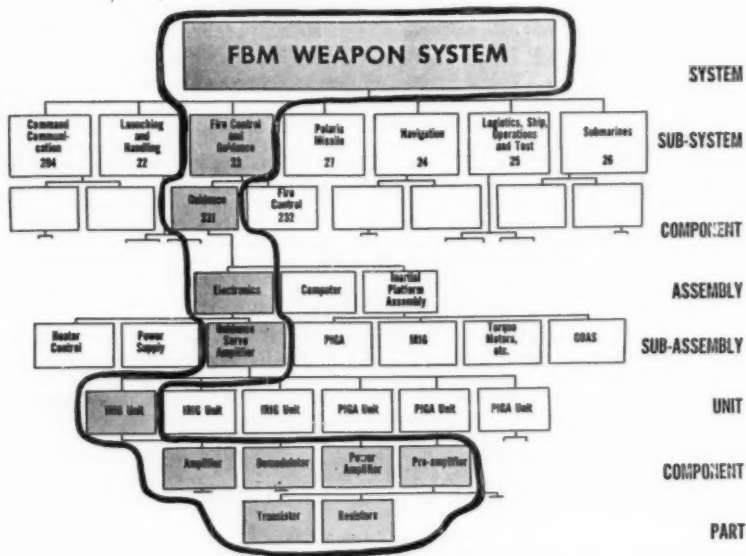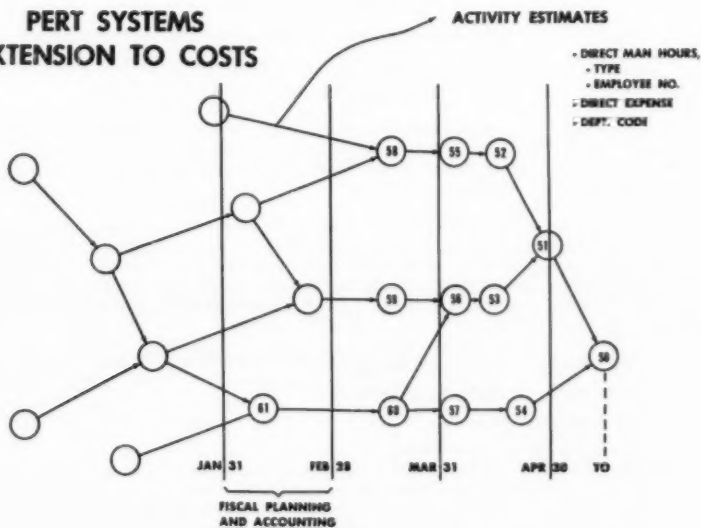 demand. Quite often in R&D, one particular designer is the only person who can do a certain kind of design job. It is desirable that he not be given too many tasks to perform concurrently.

The vertical lines in Figure 11 illustrate the problem of making PERT cost data compatible with regular fiscal practices already in effect. It is seen that planned activities cut across the orderly monthly accounting periods shown. It is possible to convert from PERT activities to financial planning and accounting by knowing the rate of expenditure, but it is not possible to work in the other direction in the absence of a PERT diagram. This then is suggestive of the proper order of application. In short, PERT costs should be considered an input to current accounting systems.

With data obtained as indicated, the following output reports are then possible in a company using the basic PERT cost approach:

- Expected Manpower Requirements
  - by skill, month and dept.
- Individual Man Loading
  - by month
- Expected Project Direct Costs
  - by skill, month and dept.
- Regular PERT Time Outputs
  - slack areas
  - critical paths
  - expected calendar time, impact prediction

Figures 12 and 13 show some of the types of data available from the cost system. It is noted that PERT Costs and Budgeted Costs may not always agree. Generally, PERT Costs will be lower and displaced in time due to the fact that all direct work may not be easily identified with networked activities.

In summary, PERT costs are being used to determine manpower requirements by both skill, time period or month, and the department. In several applications, technical directors have found they have overlooked certain technical skills and this has set up the need for looking for additional people in that skill category. Individual man-loading by month, expected project direct costs by skill, month and department are available outputs.

Cost outputs are being used in company planning for the following purposes:

1. Determining and improving utilization.

2. Balancing the work load.

3. Evaluating Cost-Time tradeoffs.
   When the first PERT cost outputs are available and management has used them in improving utilization and balancing the work load, there will be other opportunities to reallocate resources to activities or to apply new resources. The effect of these in regard to the over-all schedule, or time objective, may be easily evaluated by a simulated change, with the increment costs known. The effectiveness can be measured in terms of the time reduction to be achieved.
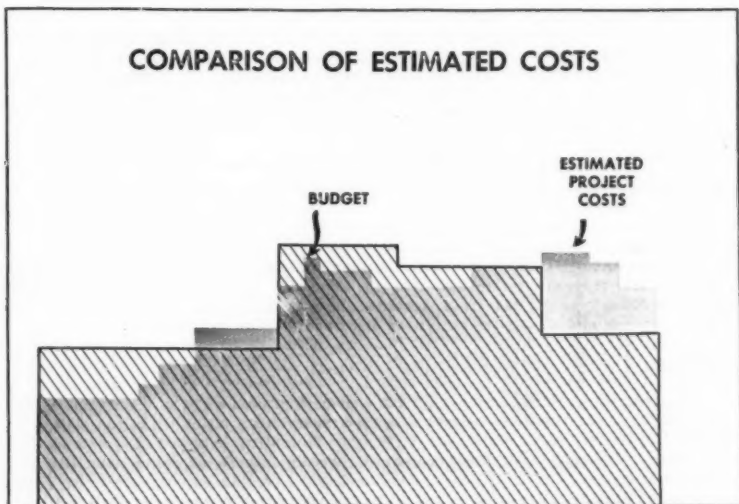
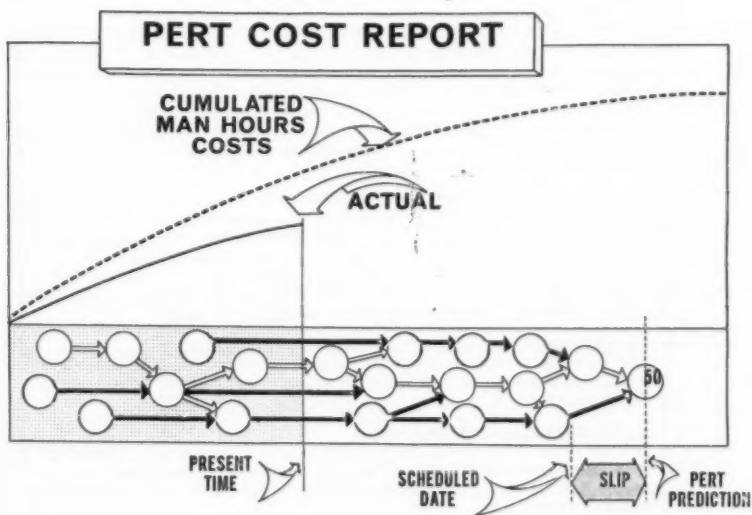FIGURE 12 -- PERT Costs vs. Estimated Costs

FIGURE 13

4. Determination of per cent of directed work.
   In the course of planning any project there will be peaks and valleys in the requirements for the services of individual skills and individuals in particular. Where knowledge of this can be ascertained in advance, the time may be scheduled for other productive work that the company has available or desires to do--such as a directed research effort. Further, this per cent is a good project control device for management.

5. Scheduling of manpower build-up.

6. Identification and assignment of technical work.

From the above it can be seen that the PERT network is capable of supplying basic information useful in planning, that this information is consistent with the definition of the planned and scheduled activities, and that it is possible to utilize this information in normal fiscal channels. It appears that this approach, which may be called "operational accounting", in the R&D field, provides the necessary bridge or "common language" between planning and scheduling activities and fiscal accounting requirements.

Performance

Turning to the third component of the management problem, the "third generation" if you please, of the Polaris management system research activities--this has been titled Project PRISM, which stands for the Program Reliability Information System for Management. The objectives of the project are twofold: (1) To develop a capability to provide performance tradeoff information concerning the program approximately two years in the future, and (2) To develop a capability to quantitatively depict the expected reliability at the subsystem level.

Two basic approaches in developing program reliability information are under consideration at this time by the project:

1. Monitoring development plan compliance, or the RMI method (Reliability Maturity Index). Under this method the development cycle as shown in Figure 14 is monitored to see that test specs, test procedures, acceptance procedures, etc., are written in accordance with the schedule set up. Each item of an assembly is rated in accordance with the factors shown in Figure 15. Check lists are built up for each of the rating factors shown, permitting a rating from zero to 1 to be assigned. The composite rating for each item represents an index of the reliability maturity. Management use of this information is directed toward low indices and zero compliance areas by appropriate sorting routines and report displays.

2. System reliability prediction. The RMI method provides a measure of compliance and does not develop a numerical forecast of the eventual operational reliability of the end item. Since one of our most needed capabilities is the prediction of the eventual logistic requirement and operational up-time to be realized in practice, it is desirable to obtain a forecast number that can be used as a planning factor. The SP research program is developing a method known as RPM (Reliability Performance Measure) involving the following steps:

   a. Development of an operational model of the FBM System.
      This model is used to estimate the per cent of successful launchings and utilizes data available from analyses of performance at each phase of the development cycle.

   b. Development of methods of analysis.
      Analysis methods are being developed which will predict reject rate and fleet failure rate. Different methods are required for preliminary design, design development, manufacturing logistics and operational phases of the development program.

   c. Development of a method for synthesizing component and subsystem estimates into a total system estimate.
      The reliability estimates are made for various components, and subsystems are combined to make a total system reliability estimate (% successful launches).
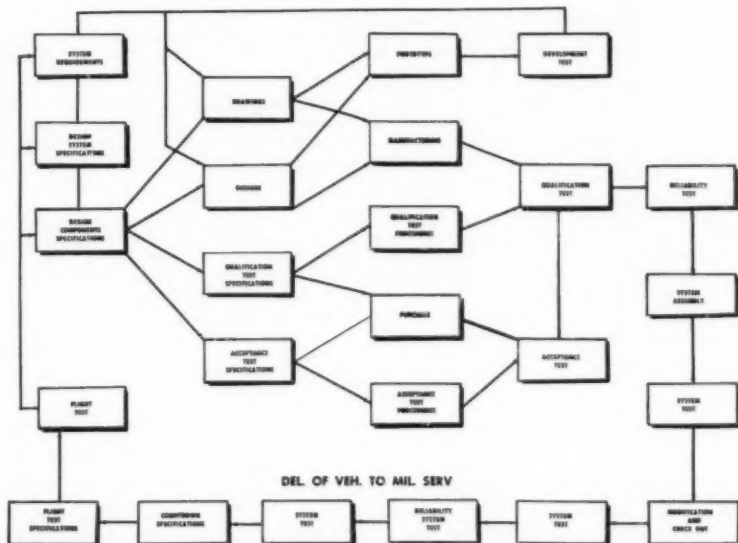
FIGURE 14 -- Missile Development Cycle as Planned

FIGURE 15 -- Reliability Maturity Index (RMI)

d.   Development of an information system.
     A rapid means of collecting, analyzing and reporting information to
     technical managers is being developed.

e.   Comparison with reliability requirements.
     Using the predictions of item (d), it will be possible to compare the predicted
     reliability with the reliability requirements, or goals, set up in the original
     technical plan. Further, use of the computer model will permit the effect of
     changes in the failure rates of components and subsystems upon the total
     system reliability to be appraised.

As these concepts are developed, it will be possible to provide management with a set
of tools that will aid in enforcing the development plan, also a quantitative number pre-
dicting the reliability of the item under design will be available at all stages in the
development project. From this number it will be possible to detect weak spots in the
program and to initiate specific remedies. Figure 16 illustrates the objective of the
reliability information system to focus on the ultimate use at all times during development.
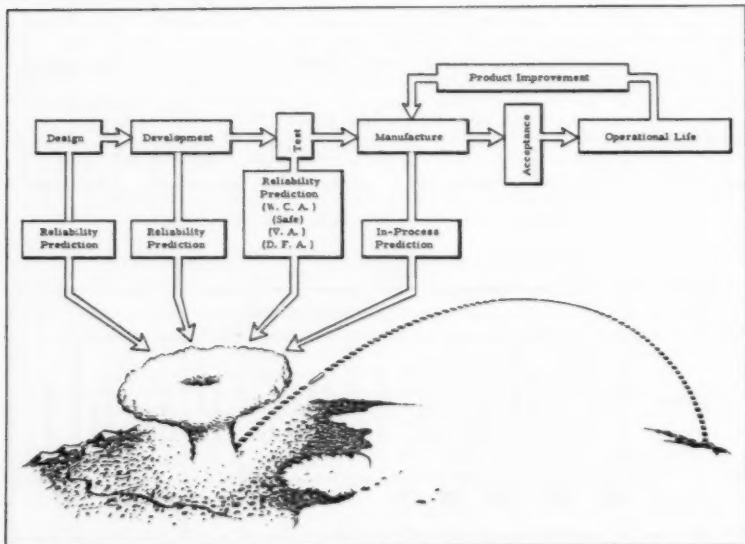
FIGURE 16 -- The RPM Function

Here again it should be noted that the management information system purports
only to develop information and does not make decisions. In short, the concept is
conceived to aid the decision maker and not to replace him. It should be further noted
here that there are many pitfalls and problems in devising an appropriate reliability system.

Industrial Applications of PERT Approach

The PERT approach is being experimented with in a number of industrial areas.
One that is under way in one of our large companies is attempting to utilize the PERT
approach in the new product process. American industry is putting more and more money
in research and has a major problem in determining whether it is getting a payoff on this
investment. Further techniques for planning and controlling R&D functions are still

embryonic in nature. A way to predict and plan for the timely and efficient exploitation of company research results is most needed. Figure 17 depicts the steps in developing a new product--a process that takes about 6 to 7 years for the average new product.

THE NEW PRODUCT PROCESS
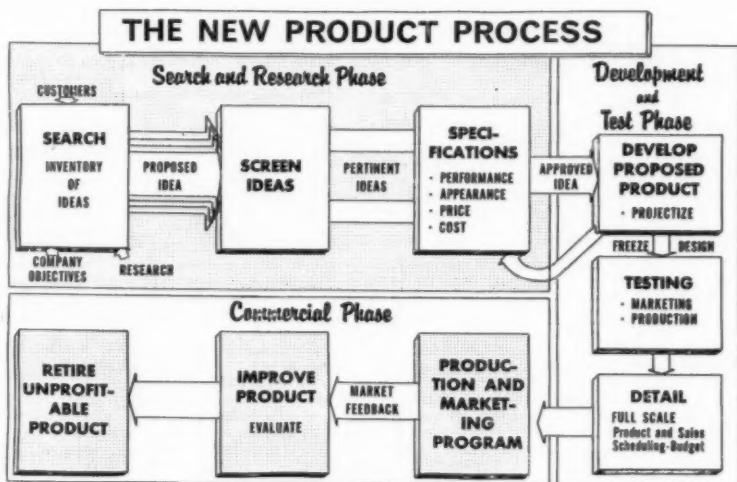
FIGURE 17

First, there is the task of searching out ideas and doing fundamental research. There are three areas shown in the Search and Research phase. The next phase is the broad area of development and test, or the development test phase, where selected ideas are brought up through reality of a pilot product. Coordination with the various other functional areas in the company is most important at this stage. The marketing, engineering and manufacturing areas all get involved because each has an eventual responsibility. Finally, if the test product is deemed feasible, it is moved into the commercial phase where it becomes a part of the product line. Out of 400 or 500 ideas, only one or two ever reach the commercial phase.

The objective, therefore, in research and development is to attempt to get the new product process performed efficiently and in a minimum time. Yet, in many companies the mode of organization works against getting new products out in a reasonable time.

Figure 18 represents such a typical industrial concern which is functionally organized--top management with sales, research engineering, distribution and production shown, each having a say about everything that goes on in current operations; research generally responsible for coming up with the new ideas and hopefully having them well enought brought out so they will move on into production and sales quickly.

Across the bottom of Figure 18 this new product process is shown--the search, screen, specification development, testing and commercial phases. Superimposed over these phases is a PERT diagram in the aggregate that shows the searching for ideas, selecting of promising ones for further refining, specifying what is to go into development, performing development tests. Moving across to the right represents the passage of time, with the lines coming down from the top in spider-web fashion indicating that almost all of the functional areas get involved in each of the various phases. Generally the various functions are not involved in a coordinated way.
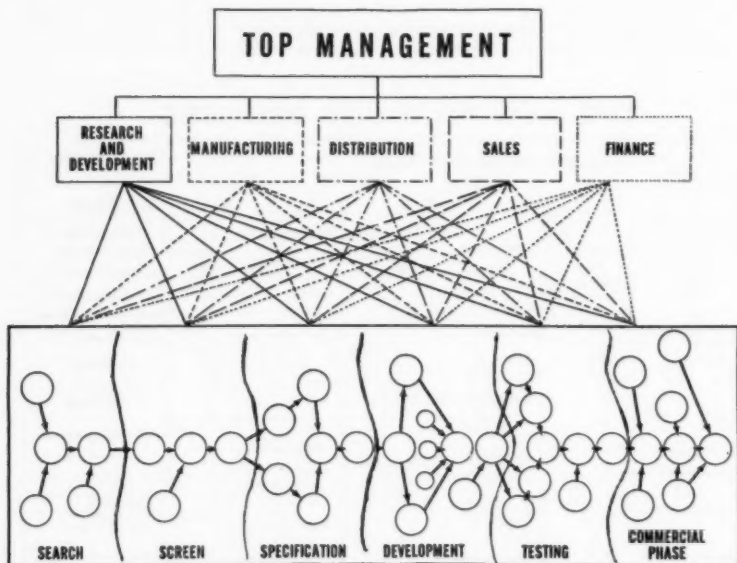
FIGURE 18 -- Project Planning in a Functional Organization

The idea of creating a project management concept for the product early in the game and using PERT as the management tool to cut across the functional lines appears promising and follows logically after a project network is set up. This use of PERT will have an effect on the traditional functional organization. Some refer to this as turning the organization 90 degrees and focusing on the project objectives. A project manager is required who can reach out for the necessary staff and systems analysis he needs all throughout the program. In this way the whole organization can be coordinated and brought to bear on new product objectives.

The companies that are involved in this confidently expressed the fact that they believe they can cut the cost of the development of new products by at least 20%, both in time and cost, due to better coordination between the functional areas of the company early in the game, on a planned basis, where everybody knows what their function is to be.

Several other applications of the networking concept have been suggested-- long range planning, maintenance and construction activities, to name a few.

In conclusion, the PERT approach offers opportunity for industrial engineers to develop better planning and control tools to aid in the management of the R&D process. Such predictive controls are vitally needed to unharness and realize the benefits of American R&D more efficiently as well as quickly.

PROCESS AND QUALITY CONTROL FOR MANAGEMENT

Walter T. Hayter, Quality Control Metallurgist
The Youngstown Sheet and Tube Co., East Chicago, Indiana

At no time since the advent of the Industrial Revolution has there been so great a need for improved efficiency of production. By this we mean higher productivities, higher production, better yields, and better quality.

This need has been brought about primarily by a rapidly changing economic climate. Labor gradually has been receiving a larger portion of the sales dollar; transportation costs have increased to a high level adding to the cost of all products used in the process of manufacture; foreign competition in the steel and other industries has made quality material available to the American market at selling prices often below that of our domestic manufacture, and dynamic foreign manufacture and sales have adversely effected our export business.

In addition, the high cost of new facilities and the unrealistic amortization rate of these facilities pose new needs for greater efficiency. Actually the rise in the stay even cost is increasing at the rate of billions of dollars per year. This is partly because capacity has expanded and there are more plants to be kept up.

Next we have the increasingly critical quality demands by our customers and the effect of automation upon these demands. High speed facilities such as can lines making 600 or more cans per minute, automatic punch presses making 50 or more parts per minute and progressive die setups, demand more uniform quality than ever before. One of the results of this demand for more uniform and dependable quality has been noted in the automobile industry. In 1961, automobile manufacturers found it necessary to increase the period of their product guarantee far beyond that of previous years.

Last, but not least, we have increasing demands for more uniform quality on our own processing unit. As each of our finishing units is improved to produce at a higher speed – such as electrolytic tinning lines at 2500 feet per minute, continuous annealing lines at 1200 feet per minute, cold reduction mills at 7000 feet per minute, and hot strip mills at 2000 or more tons per turn – it becomes increasingly necessary to have a more uniform product of better quality entering each unit.

The total of these increases in labor, transportation, facilities, and tax costs, coupled with low cost imports and improved product quality demands, forces upon us this need for efficiency and more efficiency.

We, at The Youngstown Sheet and Tube Company improved the efficiency of our operating units by application of a principle which we call "continuity of operation".

This is a method which increases productivity, production and yields and enhances product quality available for shipment. In effect we have found it makes better use of equipment and man hours. Simply stated, this principle is that on any continuously producing unit, discontinuity of production during scheduled operating hours adversely affects costs, productivity and quality. Interrupted production results in less production per man and machine hour worked or lower productivity which is finally reflected in higher cost per unit of production. (Figure I). If such interruptions were to continue for a long period of time, more producing units conceivably would be required to produce a given amount of material.

Discontinuity of production has a definite effect upon quality. This can be demonstrated by its effect upon electrolytic tinned strip for use in making tin cans. This type of unit produces tin plate in coil form, with coils welded end to end to form a continuous ribbon. Delays, or discontinuity of production for any reason results in overpickled plate, excessive tin coatings, burned, stained or damaged tin plate with the end result of more rejects and secondary plate.

Discontinuity of production and resultant poor quality can result in customer disappointment and disrupted schedules in his plants. Material rejected for off quality due to production difficulties requires reordering and rerolling and causes delayed shipment. Broken promises are long remembered by a customer sorely in need of
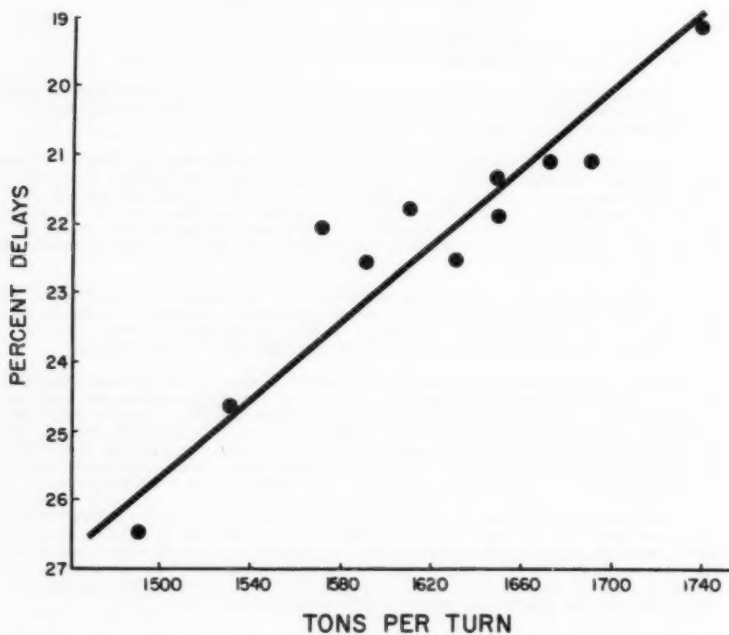
Fig. 1 - Relationship between delays and productivity on a 54-inch hot strip mill.

material. This particularly is true in our present era of closely watched inventory control. Discontinuity of production, particularly in this day of large unit product, such as steel shipped in coils creates the possibility of customer complaints and claims due to defective material which must be shipped in order to retain the entity of the coil.

Methods of achieving greater continuity of production were worked out in our plants. These required careful analysis of production records - always searching for basic causes of production discontinuity. In general, there were found to be 4 basic causes of discontinuity - mechanical, electrical, operating and outside as shown in Figure II. Most time was found to be lost due to the larger recurring types of delays such as bearings in the mechanical group, motor problems in the electrical group, roll or size changes in the operating group and power failure in the outside group. The balance of lost time in each group consists of many small recurring or non-recurring delays which can consume a considerable amount of down time. It was found that extreme care is necessary to see that all delays are categorized properly and that standard terminology is used in recording delays. As in any work involving the use of statistics, it is axiomatic that reliability of data is of prime importance.

Once our delay reports were set up, we set about to determine the individual effects of given delays upon quality. This was done by careful studies of quality factors found to be outstanding in our quality control records and yield figures. All were assessed carefully and fed back through proper reporting channels to minimize the occurrence of defect producing delays.

Gradually the work of delay analysis and control was turned over to the Production Departments and we, as quality control people, were able to concentrate our efforts to the direct quality factors and to report our findings so that corrective actions could be taken. This required a period of transition during which reports were carefully and gradually changed. However, at all times, we emphasized that production discontinuity problems would have a pronounced effect upon our total quality.

With our wide background of information on production variables, we used statistical methods to arrive at expected ranges of variation in percentages defective of the various products. These included norms of variation in solution values, sheet count, chemistries, gauges, etc., all of which are prime quality factors. This information was incorporated into our routine reports.

In order to keep management properly and promptly informed, the Quality Control Department of The Youngstown Sheet and Tube Company issues routine reports on a daily, weekly, monthly and semi annual basis. These reports, in general, are divided into steel plant and flat roll quality reports.

Information contained in the steel plant reports includes a relatively large group of unit and category data variables.

1. Ingot to product yields by unit and class of product.
2. Unit yields by product.
3. Productivities by class of product and total.
4. A group of blast furnace figures such as
   a. Distribution of silicon values by blast furnace.
   b. Distribution of sulphur values by blast furnace.
5. A group of open hearth quality factors such as
   a. The percentage of leaky pours for each shop.
   b. Off heats by shop.
   c. Causes and percentages of furnace switches.
   d. Causes and percentages of diversions.
   e. Tap to tap and other furnace time factors.
   f. Deviations from prescribed metallurgical temperature specifications.
   g. Deviations from good mold preparation practice.
   h. Chemical variations.
   i. Tap to blooming mill delivery time variations.
6. Steel cleanliness as indicated by microscopic examination.
7. Steel problems in each of the various finished products.
8. Merchant mill factors such as percentage inspected, diverted and rejected.
9. Galvanizing coating weight test summaries.
10. Causes of rejections and defects of all finished products.
    Some of the items covered in our flat rolled reports are:
    1. Slab to product yield comparisons.
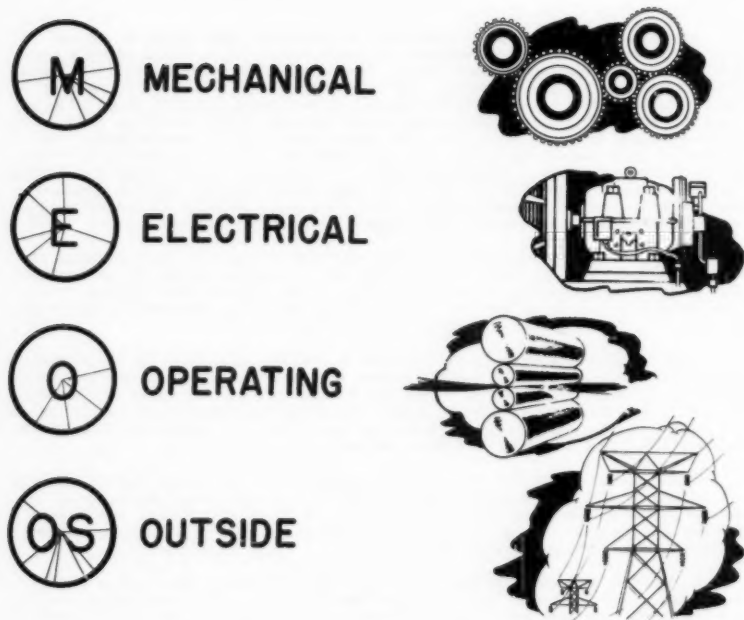
Fig. 2 - General groupings into which all delays are divided.

2. Unit yield comparisons.
3. A group of hot strip quality factors such as:
    a. Finishing and coiling temperature deviations from aims of specifications.
    b. Results of conveyor roll observations.
    c. Results of slab surface observations.
    d. Percentages finished product defective and causes of defects.
4. Continuous pickler solution chemistries which affect special surface properties
    of tin plate.
5. Cold reduced sheet mill quality factors such as:
    a. Distributions of finished gauge.
    b. Lubricity of rolling solutions.
    c. Percentage of weld breakage.
    d. Distributions of Rockwell values.
    e. Percentages defective and causes of defects.
6. Batch Annealing:
    a. Distribution of individual charge temperature ranges.
    b. Temperature range distribution of individual furnaces.
7. Continuous Annealing:
    a. Variations in HNX gas flow percentages.
    b. Variations in H_2 percentages.
    c. Variations in dewpoint percentages.
    d. Distributions of Rockwell values.
8. Electrolytic Tinning:
    a. Tin coating weight control limits.
    b. Oil film percentages within range.
    c. Percentages of OK product off the shears and causes of held plate.
    d. Source analysis of waste-waste.
    e. Special surface property test values such as Pickle Lag and Iron Solution
       values.

These are only partial listings of quality and process factors listed in our several reports. However, it will serve to give an idea of the wide range of information disseminated routinely to all levels of management from foremen to vice president.

The gathering and reporting of statistics certainly is not new to the steel industry or to any branch of man's economic life. As far back as 300 A.D., the Roman Emperor Diocletian set his statisticians to work and they evolved a system of economic controls which were meant to be used uniformly throughout the Empire. Statistics concerning ingot tons produced, cost of production and amount of material shipped have long been published in the steel industry. However, the dissemination of a complexity of quality control information to all levels of production employees is a new idea.

We are not sure how readable were the reports issued for Diocletian's edification - but we are sure that those intended for the use of all levels of management must be in such a form as to attract attention to information pertinent to problems of manufacture and quality. A routine quality control report which resembles a stock quotation listing with codes and excessive detail will not be used effectively.

Our reports are presented in such a way that the busy man can identify danger areas immediately and just as readily detect areas of increased quality performance. This partially is achieved by the use of colored ditto and photographic papers using red for the areas which require attention and green for those which have improved. White papers identify those areas in which no changes have taken place and conditions reflect production of normal quality.

The use of charts in our reports enables management to compare the period of the report with previous periods and note the effect of changes in equipment and other process variables. In addition, each report has a cover letter which gives a one sentence summary of each major factor contained therein. Cover letters are divided into two sections indicating in one those factors which are in good shape and in the other those which are not so good. Our monthly reports have an additional cover page which contains a quality propaganda slogan such as "Quality Work Assures A Good Reputation" and a well designed cartoon which portrays the meaning of the slogan.

In order to add to their effectiveness, quality control reports at The Youngstown Sheet and Tube Company are published to a schedule so that all information will be timely and fresh. We believe this is one of the reasons for acceptance of our reports by all echelons of management. They realize they are not looking at information so outdated as to be valueless in their current operations.

Many other effective methods are available for use in presenting the process and quality story to management. Use of the instant-picture type of slides for quality and production meetings often enables our Quality Control Department to demonstrate their story with pictures taken in the mill only minutes before any meeting.   Such slides countenance no argument. The picture clearly indicates the factor producing poor quality almost at the time it happens. Whenever possible, slides are shown in color - which is not as difficult as it sounds. There are simple vegetable dye coloring methods which can be used on black and white negatives - and the results are attractive.

The use of demonstration boards permanently installed in conference rooms is of great use to inform management. Large charts can be tacked to these boards and important quality and yield information kept before any group using the conference room. Quality is the business of every employee and no opportunity should be missed to present the quality story.

In addition to presenting statistical information, there are other means of instilling the spirit of quality in all levels of employees, including management. At least once each month we publish a "Quality Gram" throughout the plant. These are one page issues containing an original message showing how cooperation, teamwork, effective use of quality data or adherence to specifications can help our company by improving quality. Our "Quality Grams" often contain a picture of the subject discussed or a photograph of a defect or product damage, asking the question "could you have prevented this?"

To summarize our thinking on the matter of process and quality control, we are convinced that efficiency, productivity and quality improvements can be made through the effective studies of and wide interplant publicity concerning production, efficiency and adherence to standards set up through scientific studies. This best can be done by using accurate and imaginative techniques of gathering, interpreting and presenting data. Information gathered should be presented regularly in simple form, using graphic means when possible, to everyone concerned from foremen to vice president. All of this is done to create an interest in doing a good job - remembering that every man inherently wants to be proud of his work and that properly placed publicity will aid him in doing so.

Persistence in presentation and insistance upon conformity to standards, drawing upon imagination as an aid and tool can provide the means of achieving the goal of efficiency required for today's necessary economic manufacture. We believe with A. S. Osburn "―― knowledge becomes more usable when imaginatively synthesized and dynamically extended."

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GETTING STARTED IN STATISTICAL QUALITY CONTROL

F. Alex. Gnaedinger
Superintendent - Product Standards
Canadian Celanese Limited

You are at a "Basic Concept" session of the Fifteenth Annual Convention of the American Society for Quality Control. As the speaker commences, he is interrupted by a voice from a front seat -

"My name is Harvey Blank and I have a question". -

"Yes Sir"

"I am the Supervisor of the Quality Control Laboratory of the Dandy Handy Co. Ltd. We make Phoiphoiners, you know".

"Yes Sir"

"I received your mailed announcement. The theme 'Greater Quantity - Better Quality - Lower Costs' certainly appealed to my boss. He's the Vice-President of Manufacturing. Naturally he's interested in reducing waste - making a better product and lowering his costs. We make Phoiphoiners, you know".

"Yes Sir - But you had a question to ask".

"Yes, I did. I think it's of interest to others like myself who are here to-day. What's the gimmick? I mean-how is it done? We already have Quality Control established in our operations. We pride ourself on the quality of our product. We make Phoiphoiners, you know" -

"Frankly Sir, Phoiphoiners mean nothing to me" -

"Surely this isn't so. Phoiphoiners are these rounded dice for gamblers that would rather play marbles" -

"I see - but to continue your question"

"I'll agree that sometimes we run into trouble and our throw-outs are high, which result in higher costs. On occasion, we get the odd complaint. However, generally speaking, we do not do too badly. Nevertheless my boss, and I, are curious. How can we do a better job?"

"Well Sir, you have just completed the first step in finding out how to do a better job. That is, you've come to this Convention in order to seek help and information. Are you familiar with Statistical Quality Control?"

"I've read some references to it in current trade periodicals. But statistics - statistical' That is for the long hairs the Doctors of what-not, government bureaus and the like Isn't? We make Phoiphoiners, you know".

"I know"

"Besides the applications I've read about are in steel, aircraft, textile, chemical, business office applications - etc. Our problems are much different. We make Phoiphoiners. You know what Phoiphoiners are?"

"I thought I did".

"They are those small ladders, without steps, for washing the windows in the basement".

"I see"

"I don't think that this statistical stuff is for us".

"You know, Mr. Blank, it is surprising the variety of reaction
that the words 'statistics and 'statistical' produce in people. If you
will pardon my observation, you appear to have reacted in typical
fashion. Don't feel badly about it, however. Note that the Society,
which is sponsoring this and other international meetings, has for
reasons of its own thought it prudent to make no mention of the word
statistical in its formal name. Rather, it is simply called the
Society for Quality Control. Yet as you will see, it is from this
word that the power and success of your undertakings will stem".

"Are you saying, that my boss and I should become statisticians?"

"Definitely not. If necessary, as you get into the thing, you may
find it useful to employ someone with formal statistical training. But
in the first instance, the most important thing is to have an apprecia-
tion and understanding of the statistical philosophy or the statistical
viewpoint. The beauty of it lies in its simplicity and universal
application. Simply, it is a manner of thinking which does not require
any prerequisite of mathematical or technical knowledge".

"Then in getting started, in Statistical Quality Control, you con-
sider that the most important thing is to recognize that a new viewpoint
exists for handling problems".

"Mr. Blank - you are so right. How deep you want to go into the
subject will depend entirely upon your level of responsibility. Your
boss will probably only want to become acquainted with the philosophical
aspects. You will want to understand something of the statistical
techniques and methodology".

"O.K. so far, but how does this fit in to making Phoiphoiners more
efficiently?"

"That Sir, is precisely why I am here. If you would stop and
reflect a moment, I am sure that you would agree that there is one by-
product of any industry, business or processing operation that's common
to all. This by-product is the numerical facts that are systematically
collected.
Facts in the form of figures appear in every phase of our operation.
Production line personnel continually make checks on machine operating
conditions. Temperatures, pressures, volumes, speeds, atmospheric con-
ditions in the operating areas, etc. are measured and reported.
Quality Control and Laboratory Technicians sample and test the incoming,
in-process and out-going material.
Industrial Engineers measure and express numerically man's productivity
in units of out-put per unit of time.
Accountant's figures measure and record the financial "Facts of life" of
conducting the enterprise.
You can readily see that the data sources seem to be different and limit-
less. But it is more important to note that a common problem exists. It
is this - how can we extract the proper meaning from all the figures that
are collected.
It is also important to realize that the problem does not recognize any
industrial boundaries".

"Well it certainly does become confusing at times trying to make
sense out of all the figures that are collected and go over my desk in a
day. These I guess are statistics".

"They are, Mr. Blank, and sooner or later you will come to
appreciate the fact that many of your problems do not lie in the tech-
niques of manufacturing Phoiphoiners but are statistical ones arising out
of the data you collect. It is a sad fact, but true, that most of us do
not receive any formal introduction into the most efficient way to collect
and utilize data. We have, perhaps, not distinguished the difference
between the ability to account and do simple arithmetic, and the ability

to interpret the numbers and decide when it is definitely safe to say
one thing or another.
Fortunately this situation is easily remedied. You are particularly
interested in quality control. There are many good books on the market
to-day that cover the application of statistical methods to quality
control problems. In addition, evening or day, elementary or advanced
courses, sponsored by the Society or Universities are available in your
community. Keep one thing in mind, though. Books and courses tend to
emphasize the mechanics of the statistical method. Most beginners
master these easily. In their eagerness to get started on the "better-
ment" trail, they collect data, calculate the required arithmetic means
and measures of variation and set-up control limits as the manuals set
forth. But in the process, they often fail to consider the underlying
philosophy".

"Well, what is this statistical quality control philosophy?"

"You will agree, Mr. Blank, that the use of statistical methods
implies collection of data. The philosophy of statistical quality
control rests on the assumption that the collected data constitute a
sample, and that on the basis of the sample, some useful decision can be
made regarding the character of the data source together with a compari-
son decision regarding preferable action on the source.
This simple thought leads to a powerful method of investigation. For in
the process, you will have to consider, what kind of data describes a
situation which is in control, whether the data can be used to predict
future performance, and how best to collect and use the data to illus-
trate degree of control".

"O.K. I buy my book, take my course, am steeped in the fundamentals,
then what?"

"The next thing to do, Mr. Blank, is to find a starting place to
put the new view-point to work. This will involve a general assessment
of your present manufacturing position. It is highly desirable that you
examine the amount of money you are losing in waste, process reworking,
or quality complaints. This study will pin-point the most profitable
area in which to operate. The economic survey should also be supple-
mented by first hand information from fellow production supervisors and
your boss. However, the most important thing to remember is to pick
only one specific problem and concentrate your resources upon it."

"From your experience, where do you think the most profitable and
effective operational area is?"

"Undoubtedly the most spectacular advances are made when statistical
thinking is used in conjunction with process control through product
testing or visual inspection. It should be self-evident that the place
to control product quality and minimize waste is when manufacturing is
taking place. The hope of any control procedure is that trouble will be
recognized promptly and then rectified. To do this, measurements of one
kind or another are taken. The facts that are collected are used to make
decisions. Decisions may have to be taken by the operator, the foreman
or the department management. With your newly acquired statistical view-
point you can help them make better decisions and thus contribute to more
effective manufacturing practice. In addition, and this is important,
with the use of charted data on the manufacturing line, trouble can be
identified, anticipated and avoided".

"Then how should I proceed?"

"Having stated the problem you must ask yourself what is really
taking place during processing. In order to find out, you will want to
collect some vital statistics, usually resorting to sampling techniques.
This in turn will lead to the consideration of some important questions.
It is appropriate to mention some of them at this time.
The approach, fundamental and logical as it may seem in retrospect, is
sometimes missed by investigators not trained in the statistical
philosophy".

How to Measure?

A leading question to be considered is, if and how can you measure
the particular processing aspect that you are interested in. You must
get things expressed in terms of numbers. This is simple when you are
measuring things on numbered scales like weight, density, length, time,
etc. or events that can be classified as good or bad, present or absent.
Sometimes, however, abstract qualities must be measured and it will test
your ingenuity to convert them into some type of numerical yard stick.
As a laboratory Supervisor, Mr. Blank, you must consider whether your
laboratory tests fulfill their intended end-use. Can you distinguish
one situation from another with your test? You will want to know, not
think you know, what the precision and accuracy of your tests are.
Precision can be measured quantitatively. In many laboratories it is
included as a part of the specification for the analytical procedure.
Quality Control of laboratory techniques are just as important as
process control. Many laboratories use a quality audit program with
control charts in order to effect this. It is surprising when conduct-
ing investigations to note the misconceptions that exist, in this area,
by laboratory personnel. In some instances, production personnel are
blamed for fighting losing battles whereas it is in the analytical
laboratory that the fault lies".

"I suppose that the same thing is true for the visual inspection
procedures on the production line".

"Yes, Mr. Blank it is. Process problems often arise out of
differences that exist in specification interpretation by visual
inspectors.
The point to be made now is, I think, that during the quality control
investigation, the data producers must be studied, for the decisions
to be made can be no better than the data that is collected".

What to Measure?

There are some important things to remember when you are getting
started in your process sampling investigation. All sampling enquiries
are aimed at discovering something about a particular data source. Be
sure you define the source that you are interested in. You may be in-
terested in knowing what is happening on one spindle, one machine, all
spindles, all machines, etc. Sample the right source and confine your
conclusions to that source. It goes without saying that you should
understand clearly what you are trying to find out about the data source.
Remember that samples are usually of a limited size and so will contain
limited information. By all means take into account any prior knowledge
which can be derived from other sources.
Mr. Blank, we've been talking about some of the necessary things to con-
sider when getting started in statistical quality control. Perhaps, I
can best sum it all up for you by means of an example.

Case History

The Carter Little River Mills is a company that produces an inter-
mediate product on 288 machines. Their particular problem was to
control the number of times the machines stopped. It was generally
recognized that machines stopped, in a random fashion, for two reasons:

    1) Mechanical trouble   (Mechanical stops)
    2) Raw Material failure   (Material stops)

Stoppages for mechanical reasons could be attributed to inadequate
general maintenance or improper mechanical adjustment.
Stoppages for reasons of raw material failure could be associated with
quality problems arising out of preceding processes.
The number of times a machine stopped affected three things:

    1) Machine Job Loads
    2) Quality of the finished product itself
    3) Waste arising out of rejects due to sub-standard quality.

The Industrial Engineering Department established job loads based on the
number of random stoppages that occurred during processing. It was an
established fact that it took an operator one minute to rectify a situa-
tion arising from a stoppage. The operators were scheduled to do 36
minutes of rectification work in every hour. Thus, if the random
stoppage rate was one per machine hour, an operator was scheduled to
operate 36 machines.

Quality of the finished product was judged through visual inspection.
Each time a machine stopped, a defect occurred in the product.
Tolerances for the number of defects per production unit had been
established. Any production unit containing excessive defects was
rejected and became waste.

It is evident, then, that high machine stoppage rates were of great
concern to the plant management. When the rate was high, job loads were
low and labor operating costs increased from the fact that additional
machine operators had to be employed to run the full machine complement.
In addition, finished product quality deteriorated due to the high
incidence of defects in acceptable product. High costs resulting out of
excessive waste also accompanied this situation.
Plant Management attempted to control their operation through the use of
"stoppage checking" techniques. "Stoppage Checkers" were employed who
went out into the plant and made two-hour checks in the operating area.
Their assignment was to observe the number of machines tended by one
operator. They noted the number of times each machine stopped during
the check interval. They also attempted to assign the reason for the
stoppage, that is, whether it was for Mechanical or Material reasons.
After each check was made, the check sheet was handed to the department
foreman who was responsible for seeing that the report was followed up.
If the mechanical reasons seemed to be excessive, the mechanic in charge
of the offending machinery was notified.
This was the well-established control technique. Generally speaking it
was most effective. However, the day arrived, when the Higher Management
passed the word along to the Plant that under to-day's business con-
ditions, operating costs were considered to be too high. Labor costs
were pricing them out of the market. Complaints of quality, arising out
of competitor comparisons, were beginning to come in. Something had to
be done.
The machine stoppage problem was referred to a Quality Control Technician
who had statistical Quality Control Training. His first task was to take
over direction of the "stoppage checkers." In doing so, he noted:
  (1) some checkers could not properly identify the stoppage
      reason. This was rectified through training.
  (2) although the standard check time was supposed to be
      two hours, the check times ran from 1 1/2 - 2 1/2
      hours. The time was standardized to two hours.
  (3) times of checking were not done at random intervals.
      This was rectified through the use of a set of
      random numbers.
The sampling program was started in such a way that the entire machine
complement was covered every week. To facilitate analysis of the data,
a Control Chart was started for each machine on which was plotted the
result of each two-hour observation.
The total stops were charted on the top part of the chart and underneath
it, a breakdown of the reasons, mechanical or material, were given.
The usual method of handling the check sheets, with the production
personnel on completion of an observation were followed. That is, after
every check, the Department Foreman and/or the responsible mechanics
received a copy of the results to follow up.
It soon became apparent to the Quality Control Technician that the
greatest reason for stoppages arose out of mechanical difficulties.
Why was this?
In discussing the question with the Department Foreman and the mechanics,
it was established that they had a rule-of-thumb that they did not
service a machine unless the stoppage check on a machine indicated three
or more total stops. They had arrived at this arbitrary rule out of
experience. They had gone out to check the mechanical condition of the
machines on some occasions when 1 or 2 stoppages showed on the observa-
tion sheet, only to find that in some cases, nothing was wrong. Any
sheet with 3 or more stoppages appeared to be a safe bet.
This was the clue that the Technician was looking for and he took
immediate steps to rectify the situation. The Control Charts for each
machine were taken down to the operating area and discussed with the
personnel there. It was explained to them, that for every stoppage rate
level, there is a pattern of varying sample results. A diagram, similar
to Figure I, was prepared. From it they could see the difficulties that
arise, in attempting to make a decision for action, based on a single

observation.
It was obvious that a 2.0 average stoppage rate could easily be identi-
fied.　The problem of differentiating between a 1.0 and 0.5 average
stoppage condition was not so obvious.　Each condition could produce
a number of single observations with 0, 1, or 2 stoppages.　They soon
appreciated the fact, that single sheets with these observations on them
did not necessarily indicate that nothing was amiss, or that improvement
was not impossible.　It was pointed out that a number of results, or the
pattern of variation of the sample results, had to be considered.　This
pattern could be predicted by reference to some useful tabulations.
Control limits could be set which would define the pattern to be
expected.　When the predication was not met, something should be done
about it.　Subsequently summary charts were prepared by machines.　A
Action was taken on the machines with high stoppage rate levels.　A
mechanic's training program to improve mechanical maintenance work was
instituted.　From this and the use of charted data, improvements
immediately took place.
Stoppage rates dropped to 0.5 stops per machine hour on most machines.
It was possible to reassign job loads and reduce the labor costs by
approximately 75%.　Quality improved in finished acceptable end product
and waste was reduced considerably.

"Mr. Blank, such an example is not unusual in Statistical Quality
Control Work.The superior results were not attained through complicated
statistical methodology - but rather through a new view point - a manner
of thinking, which does not differentiate between whether or not you are
making textiles, aircraft, electronic components - or even phoiphoiners.
And this, Mr. Blank, is just about where you and I came in".

Author's Note

The reader may wish to pursue the study of statistical philosophy.
The following references are given, from which ideas have been borrowed
freely.

(1) Dr. E. G. Olds, "Some of the Challenging Questions in
    Statistical Control".　Industrial Quality Control magazine.
    Vo. XII, No. 1.　July 1955.

(2) M. J. Moroney, "Facts from Figures", published as one of
    the Pelican Book series, A236.

FIG. 1 - CARTER'S LITTLE RIVER MILLS - QUALITY CONTROL DEPT.
Stoppage Levels and their Distributions
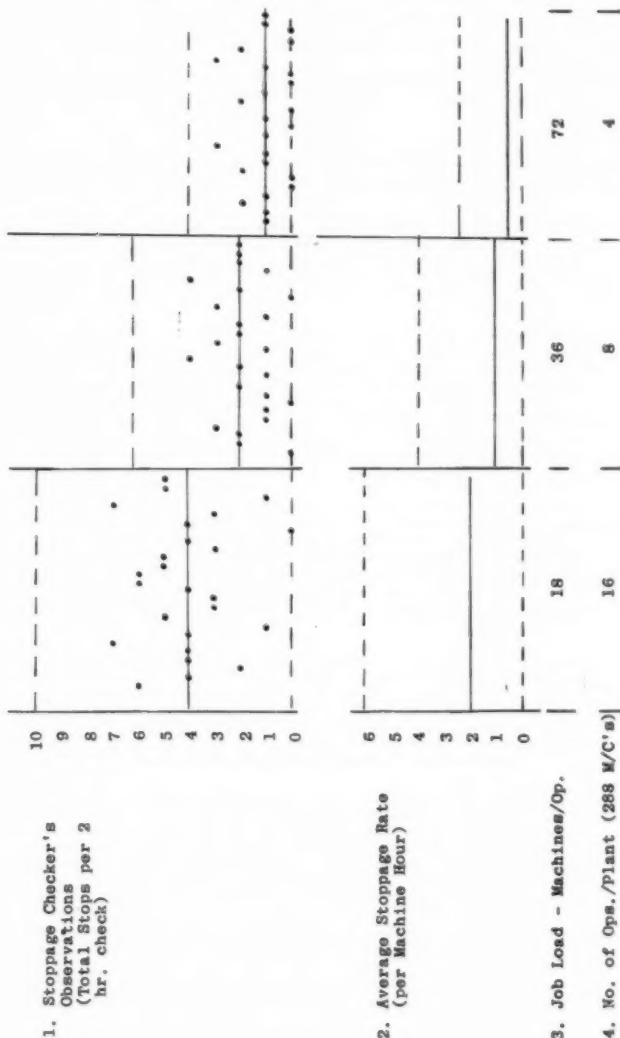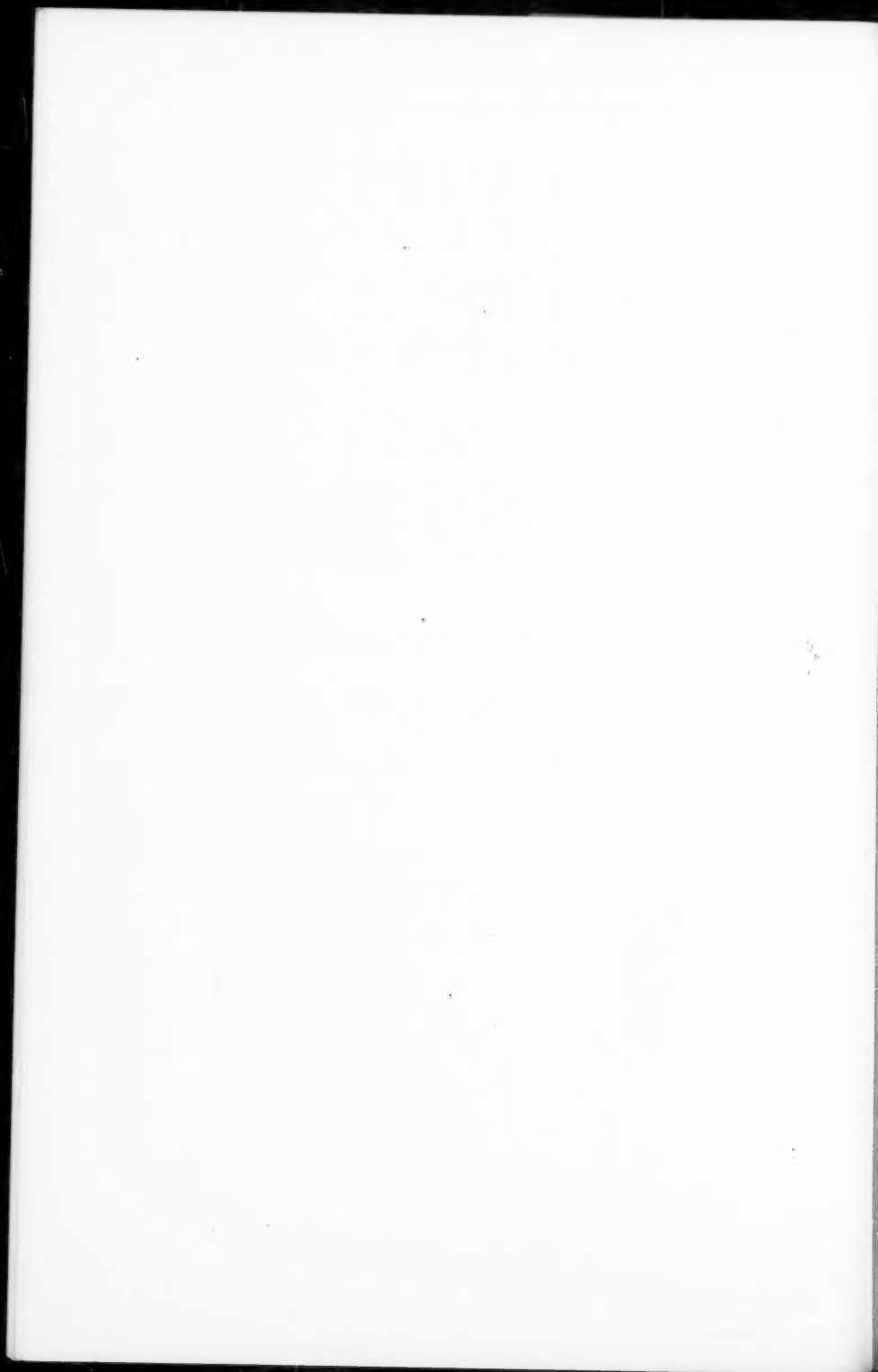
BENEFITS OF QUALITY CONTROL INPUTS IN PREPARATION OF SPECIFICATIONS

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Webster's dictionary defines the word "Specification" as, "A statement containing a minute description or enumeration of particulars or details of construction not shown in an architect's drawings."

The benefits or goals that might be cited as derived from Quality Control input in the preparation of any specification are numerous. To highlight but a few: cost, schedules, design and re-design, contracts, employment, facilities, etc. However, the main benefit where long range quality planning pays off, is the overall prevention of quality problems.

A coordinated team effort, consisting of Quality Control, Manufacturing Control and Product Design creates the perfect harmony prior to the initiation of any analysis of the product design for conditions that might otherwise create inherent quality deficiencies. Quality Control further assists in identifying the environments and end-item conditions against which the product will be evaluated. This analysis of course reflects similar designs, failure histories, field and in-service feedback which is consistently researched and evaluated by Quality Control. This information is then directed toward new specifications or modification of current documents.

Quality Control can coordinate with design groups to determine completeness of the test plan, including the tolerance conditions. By reviewing proposed engineering evaluation tests, Quality Control can estimate from adequate detail data the probability of the product to perform within established tolerances. Here Quality Control pre-preparation also highlights the probabilities of tightening or relaxing tolerance parameters for practical manufacturing purposes and environmental or acceptance level testing conditions which mainly reflect savings plus reliability to both the manufacturer and the customer.

Quality Control can coordinate with design engineers to accomplish a practical application of the classification of characteristics as required, such as major and minor.

Still another area for Quality Control in-put regarding specifications is the inclusion of data requirements for ensuring vendor participation, compatibility and capability of measuring systems, accuracy and characteristic variability.

An additional element is the verification of the completeness of specifications which often times leave much to be desired. For example, one of the undesirable or vague elements to consider would be the possibility of misinterpretation. Here again benefits are very high due to the prior practice of Quality Control reviewing drawings and assisting in specification writing. Consider for a moment misinterpretation affects on the customer, vendor, machinist, foreman, or inspection personnel. Just a little foresight, in-put and review will avoid this type of costly pitfalls.

The responsibility for planning and outlining detailed test procedures and test equipment is yet another in-put achieved by the Quality Control Department.

Quality manufacturing measurements and controls must be closely integrated and documented for maximum economy and quality prior to manufacturing process.

Other details covered by advanced Quality Control in-put are jig and fixture activities and controls on the calibration and measuring of test equipment and techniques to be utilized, certification of adequate personnel, production employee training and the initiation of new manufacturing processes and the like.

ASQC LCS Code 000:70:000

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In the case of Astronautics, a Quality Assurance Group, within Quality Control is responsible for directing the following activities:

1) <u>Quality Control Standards</u>: Rules established by industry and/or Convair Astronautics for measuring factors of quality, weight, value and quality standards are used to assure that an acceptable quality level is maintained throughout inspection and testing procedures. Standards are prepared and issued in document form, usually as a specific standard applying to all items in general within the subject.

2) <u>Quality Control Requirements</u>: Acceptance procedures prepared by Quality Control to implement specifications. Requirements are issued in documents, equipment operation procedures, or similar media. These documents are issued as part of the basic specification and in case of sub-contractors it becomes part of the procurement package.

3) <u>Quality Control Document</u>: This serialized document which is referenced by each blueprint is effective immediately upon release, taking precedence over all other Quality Control procedures and standards pertaining to the items to which it refers.

4) <u>Acceptance Testing</u>: Tests performed on individual items and individual lots submitted for acceptance under the contract. The tests verify those conditions which show conformance with specified requirements of Convair, vendor and/or customer.

5) <u>Production Evaluation Testing</u>: Are tests which use quality "sampling" techniques for testing production units to verify and maintain proper production techniques, skills and tools. They are essentially periodic equivalents of a "preproduction" (qualification) test. They expose the unit under test to all or a portion of the critical operating conditions and environments for which it has been designed.

The point of interest here is the Quality Control document, wherein specifications and measurement of quality or reliability is significant only in that means are available for its control. Such control must take place throughout the entire cycle of development of the item from conception on. This is recognized now by the number of specifications which call for reliability efforts to begin at the time of concept development.

It is obvious that these quality documents result in additional overhead and labor than would normally be applied without them. As a consequence, there is a tendency to conclude that this effort is too costly. Investigations into this phase however, indicate that this is not quite true. While direct assigned time and labor increases, the trend now clearly shows that without the coordination of Quality Control's prior inputs to specification writings, inherent inadequacies and costly reworks multiply.

It is quite obvious to us then that the sophisticated state of the art and the current electronic age is advancing rapidly. Quality Control has achieved and will continue to provide significant contributions and accomplishments to industry it services and to the public that promotes competitive business activities.

No longer is Quality Control a "behind-the-scene" operation, and better still, it has ceased to be a paralleling activity; for today we find it to be a forerunner. It is active and contributes to project conceptions throughout development and manufacturing and always current with product life expectancies.

WHY QUALITY REQUIREMENTS MUST BE UPGRADED

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A. INTRODUCTION

The psychologist tells us that we need to know something of the man if we hope to understand his thinking - his philosophy. There can be no doubt that 24 years of Federal Government service, with the last 9 dedicated to quality endeavors of U. S. Army Ordnance rocket and missile programs, will have its impact on a person's outlook. This is the background by which you should evaluate this paper.

To assure a basis of mutual understanding, it is often necessary to establish certain premise. As my thoughts are presented, please keep the following in mind:

1. Whenever "quality requirements" are mentioned, think in terms of all those things that go towards providing a complete quality program. Quality requirements are not just those things normally found in Section 4 of a specification.

2. Whenever "programs" or "missile programs" are mentioned, they will be in terms of complete, integrated, functional systems; consisting of both the missile and its associated ground equipment.

3. Whenever, "quality" or "quality assurance" is used, it will be in terms of the Army Ballistic Missile Agency's (ABMA) "total quality" concept; not just the industrial production phase.

It is recognized that many of you will immediately associate some of my thoughts with "reliability." Please bear in mind, my considerations are concerned with function - not organization. To us reliability is a phase - a most important phase - of a total quality program.

B. QUALITY REQUIREMENTS

ABMA's program of "total quality assurance" is certainly not new in concept, nor is it peculiar to Army Ordnance. Dr. A. V. Fiegenbaum has talked and written most persuasively about "total quality control" for several years. I trust you will find ABMA's approach and application of "total quality" to be of significance, and of more than passing interest.

With this, and prior premise, out of the way, let us consider some of the major "quality requirements" that make up the "total quality" package, and perhaps identify them not only as to "why" of upgrading, but also "what" and a bit of "how."

Design & Development

Just as "reliability" has its birth during development, so does "quality," and so must "quality requirements" - - a vigorous program of design - test - modify - retest - document. A "total" design program must cover more than just the mechanical and/or electronic type considerations of the component parts that go together to make a functioning system. Out design people must also have knowledge of the total picture - the complete operation. There must be an acute awareness that eventually their "brain child" will be exposed to the many vagaries of the logistical supply line, and to the rugged conditions of the battlefield. The designer must keep in mind at all times that this wonderful missile system cannot be always tested and fired by engineers under laboratory conditions; but instead by soldiers under the stress and strain of battle conditions. If the designer can keep these things in mind, along with technical performance requirements, we will have taken a major step towards our quality goals.

This is just one aspect of what we need to do in this area. Of equal, or even greater importance, are the quality standards and programs being developed by the quality engineer (contractor or Government). Now is the time to lay the foundation for the advancement of new quality knowledge - new methodoligies - new policies.

Production Control & Testing

Of all the many things we generally accept as being good quality practices, an area of particular significance is the quantity and quality of testing. The significance of the test equipment associated with our programs is of a magnitude barely equalled by the missile itself, and in many instances test equipment complexity exceeds that of the missile system. This being the case, isn't it rather incongruous to place so much emphasis on testing under Section 4 of the specification, and little, if any, thought to the test equipment, test personnel and test techniques?

If I may digress a bit, and go back to design and development; here too is another significant area requiring action during development. The design and testing, and test equipment therefor, of complex missile systems is closely interlocked and interrelated - we can't have one without the other. In those areas where the hardware is to be functional - not static - this relationship is of paramount importance. The design engineer creates his conception of what is needed to perform a function. At the same time, he creates a bread-board testing device. Only with the marriage of these two is he able to determine whether or not his objective has been achieved. If the answer is positive - he is ready to move forward. At that point in time (at the very latest) the quality engineer needs to be aboard for several reasons:

1. To assist the design engineer in reducing to writing and/or drawing all of the test requirements that have been generated. (Those that are related to test equipment and test procedures.)

2. To start the development of that portion of the procurement package (Section 4 of Specifications) that will be needed for industrial procurement. To make certain the designer's intent is properly reflected in describing the item - its functional requirements and the acuteness of its characteristics - the test equipment and test procedures to be used to determine that "intent" has been met.

3. The initiation of work for an orderly transition of test equipment from "bread-board" model to Industrial production; standardization - calibration - compatibility - human engineering - automation.

Throughout the program the test equipment must keep pace with missile hardware. The introduction of the quality engineer at a very early stage of development will provide assistance to the designer, and at the same time will assure orderly transition from development to full scale industrial production.

The development of realistic requirements for test equipment is a major area where timeliness of action and upgrading are long overdue. Adding realism to this portion of the quality requirement, based on the many essentials learned through production, test, inspection and evaluation, is one of the major contributions Industry could make at this time.

While we are in this area, I would like to mention briefly another activity where help is needed. Unfortunately some of our specifications came into being before we realized fully the high quality and reliability requirements needed for our missile and space programs. Valuable information is being gained daily through failure analysis. More and more is being learned about functional tolerances and the significance of various characteristics. All of these findings need to be reduced to complete and definitive specifications. Here again is an opportunity for Industry to perform a really vital service. We earnestly solicit your help towards keeping our specifications at a level consistent with the needs of the "state of the art."

Surveillance

There are some who say quality functions, and associated quality requirements, end when the product goes out the door. Not so in the missile game. If we are to know where we stand, and if we hope to ever elevate the quality, or if you prefer reliability, plateau, we must place more emphasis on surveillance and maintenance of our equipment. Surveillance to see just what has happened during transportation, storage, operational check-out, modification and maintenance. Our basic responsibility as quality managers - quality engineers - first and foremost is to our Armed Forces. Such responsibility must provide demonstrable assurance to them of the quality, reliability, usability, and maintainability of our weapons systems. Demonstrable evidence under the most adverse conditions - not the conditions of laboratory, factory or proving ground - but under the conditions of combat, with the battlefield being world-wide.

Management

By now you may be thinking - "these things are true, and most certainly they are important, but you are supposed to be discussing quality requirements, and requirements are things expected of someone." We readily recognize those things that can be reduced to an exact science, but the thing that is really giving us trouble is the "art" of management. How does one go about the management of such an activity? Can we reduce such quality requirements to writing, and make them a part of a specification or standard, and ultimately a contractual requirement? The more I see of our day-to-day operations wherein we are using, or attempting to use, specifications of suspect quality (adequacy), the more I am convinced that regardless of what might be written in a specification, or how well couched it might be in legal terms, unless it represents ultimately a mutual agreement between the supplier and the buyer, we might as well forego the whole thing. I am convinced the things I have discussed can be reduced to meaningful writing, and they can be made contractual. The Department of Defense specification MIL-Q-9858 is an excellent base for such a document. For various reasons MIL-Q-9858 had to be a very general quality requirement. However, I am quite sure this Society (ASQC) will have the Department's blessing, if we can come up with a supplement that will provide for better quality and reliability. This need should be a challenge to us - ASQC - Industry - Government. Will we meet the challenge?

By now some of you are probably saying - "this fellow is a dreamer. What he says is fine, but how in the world would such a program be administered?" We will do it by recognizing the program for what it is - A Top Quality Management Job. Place the quality function in its proper perspective, be it in Industry or Government. Recognize the problem as one requiring peculiar talents; engineers and specialist who devote their entire effort to quality activities.

So, what may we conclude - where do we find ourselves? Certainly many of the things I have said are restatements of basic essentials long advocated by "quality minded" people. Many of them cannot be legislated into being. As a minimum we must introduce new concepts, and continue insisting that quality requirements be upgraded to reflect current needs. Anything less would be a disservice to our national well-being.

C. SUMMARY

If a summary is needed, remind yourself to:

a. Always think of quality requirements from the "total quality" concept. Consider all of the things that must go into the program to give the troops a weapons system on which they can rely.

b. Maintain specifications at the highest possible level.

c. Insist on the proper status for the quality effort.

d. Require fully qualified and wholly dedicated people to operate the quality program.

e. The management of quality programs is not a science; rather it is an art. Perhaps poorly defined at times, but nevertheless a useful art - provided we really work at it.

SOME RECENT DEVELOPMENTS IN PROCESS CONTROL

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During the early stages in the growth of statistical quality control, primary emphasis was placed on techniques that assumed a nearly static set of production conditions. It was assumed that the process was running steadily at some fixed level unless an assignable cause entered the production system to suddenly shift the process. The Shewhart control chart (13) is probably the best known technique developed on this basis.

In recent years, attention has been shifting to the problem of process control under a set of dynamic, rather than static, conditions. Here it is assumed that some assignable causes are not merely unique occurrences that must be prevented, but are basic factors in their own right. For example, level shifts are not unexpected when different batches of raw material are fed into the process. Barnard, in his paper "Control Charts and Stochastic Processes" (2), suggests that the distribution of these "jumps" in level can be determined and considered in establishing a good control system. Where the effect of variations of this type must be minimized, Page has devised a new and extremely efficient technique known as the Cumulative Sum chart (7, 11). This technique has now been developed to a stage where it can be used with ease by both line and staff control personnel. Truax (14, 15) has illustrated this in reports of his experience with Cumulative Sum charts at the Atlas Powder Company.

In one sense, this approach can be viewed as a combination of control based on the most recent point plotted, as in the Shewhart chart, with an analysis of the trend of previous observations. This is not the complete story, but let us first examine this phase. There is a very strong similarity to sequential analysis. The deviation of each current observation from the nominal value is added to the sum of the previous deviations; these sums are plotted and compared with control limits. The limits are treated in a novel and efficient manner suggested by Barnard: a V-shaped mask, pointing forward with its axis parallel to the time scale, is placed a distance, d, ahead of the latest point, and as long as all previous points remain visible within the mask, the process is considered in control. Two parameters, the angle of the V and the lead distance, d, must be specified. These parameters are functions of the α and β risks of Type I and Type II errors, although a relatively new concept is used that replaces a direct consideration of these risks. This is the Average Run Length or A.R.L. (1, 5, 7). The A.R.L. is a measure of how long the process will run at some level before process adjustment is called for.

A good method for comparing various control systems is through the use of curves of Average Run Length functions, in the same way in which Operating Characteristic (O.C.) curves are compared. If the Shewhart chart is compared to a Cumulative Sum chart having an equivalent α risk, the Cumulative Sum chart will show a superior performance in the sense of shorter average run lengths for small and moderate shifts in the process level. That is, the Cumulative Sum chart will call for process adjustment much earlier than the Shewhart chart for process shifts less than about three sigma units from the nominal value. Sudden large shifts can be detected more quickly by the Shewhart chart, but the difference is small here since both systems will respond rapidly. The advantages of the Cumulative Sum chart in respect to smaller average run lengths will be somewhat reduced when various schemes for making use of run theory supplement the Shewhart chart, but few such combinations have A.R.L. curves that closely match those for the Cumulative Sum chart. Proponents of the Cumulative Sum system point out that the Cumulative Sum procedure has a single operating criterion and thus is easier to handle since it avoids the complexity of supplementary rules for runs.

Perhaps the most efficient use of run data is that of the "Control Charts With Warning Limits" previously proposed by Page in 1955 (9). The three sigma (or k sigma) Shewhart control limits are called "action" lines. Any single average plotting outside the action line calls, as the name implies, for immediate corrective action. In addition, "warning" lines are drawn at some k' sigma level, (k' < k), for example, at 2 sigma. If an average plots between the "warning" and "action" limits, the process is suspect, but further information must be obtained before action is required. Two decision rules that could be used would be (1) that if n consecutive points plot

between the two lines, action will be required just as for the single point outside the action line, and (2) that if n out of N points are in this zone, action will be called for. A reasonable analogy is to consider the Shewhart chart as being similar to a single sampling plan, while the control chart with warning limits can be likened to a double or multiple sampling scheme. This latter scheme has the very appealing virtue of calling for immediate action on clear-cut process shifts, but giving careful consideration to borderline cases. The Cumulative Sum chart can then be compared to sequential sampling which is the most efficient method in the sense of getting complete information from a small sample. In sampling inspection, the choice of single, double, multiple, or sequential plans depends on a balance of the cost savings due to sampling efficiency and the expenses involved in administering a testing program in which the size of the sample is a variable. The same considerations should hold when selecting a control system, but the administrative problem here is that of balancing the costs and risks involved in the length of time that the process can continue undetected at the wrong level, rather than how large a sample is needed at any given time.

An additional virtue, and one of the most important properties of the Cumulative Sum chart system, is its ease and efficiency in estimating the new process level should a shift occur (2, 11). The cumulative graph exhibits many advantages for visual interpretation of the data, both on a current basis and for post-mortem interpretations.

Another system of accumulating data to benefit from trend analysis has also been independently proposed recently. Roberts (12) has described a control chart test based on Geometric Moving Averages. Morris and Howe (6) have presented a system based on the same principles, using a different method of computation. Basically, both of these papers suggest that the latest observation is the most important single bit of information. Previous data should be averaged with it to take advantage of the continuity of the data and the process, but as the data gets older it should be weighted far less than the current point. Unfortunately, not much actual experience with these systems has been reported so that a full comparison with the Cumulative Sum chart is not possible. As in the Cumulative Sum system, the β risk is not defined by name, but the selection of the weighting constant effectively determines it. Again, the Average Run Length curves are better for these systems than for the straight Shewhart chart, when small and moderate level shifts occur. It is essential to point out that both Page and Roberts clearly state that these tools should be used only when greater sensitivity in detecting these small and moderate process fluctuations is required, and can be harmful in the sense of over-control should this not be the case.

It is also interesting that to date there has been a strong tendency to select the limits for Cumulative Sum and Geometric Moving Average charts on the basis of experience, rather than mathematical computation. Thus, the angle and lead distance of the V-mask for the Cumulative Sum chart is often obtained by plotting past data in cumulative form and shaping the V so that it catches known out-of-control situations, and does not reject periods of good production. The weighting constant for Geometric Moving Average charts can be similarly obtained by reviewing past data. Of course, limits for each method can also be computed. See (5, 6, 12) for selected cases.

As was pointed out above, the Cumulative Sum and Geometric Moving Average charts have been developed to meet the need for greater sensitivity that is found in many situations. The auther in his papers on Acceptance Control charts (3, 4) has tackled the problem of control where greater sensitivity is neither required nor desirable because of the problems caused by over-control. Here again, recognition is given to the fact that there are certain assignable causes that act to keep the process away from the nominal value, but against which protection is not feasible nor desirable. Nor is the exact distribution of the "jumps" in process level of concern.

In essence, the approach taken is to combine some of the aspects of acceptance sampling by variables with the control procedures. It is not unusual to find people using a control chart to decide whether to accept (continue to run) or reject (shut down or adjust) the process. Yet the Shewhart chart was not designed to be used in exactly this sense and no consideration is taken of the β risk of failing to detect a level change of some given magnitude. Under the Acceptance Control system, the amount of process shift we wish to accept without adjusting the process is defined along with an α risk of a Type I error. This, in effect, allows the line for the nominal process level to be expanded to a zone of acceptable processes. In addition, the amount of shift we wish to be sure of detecting with only a β risk of a Type II error is also defined. From this, the required sample size and control limit can easily be computed assuming that we have enough information to get a reasonable estimate of sigma, the within rational subgroup standard deviation. Sufficient experience has been accumulated to show that this type of chart is extremely easy to use. Of even greater

importance, because thought has been applied in the selection of acceptable and rejectable process levels, it is being used more rationally than had previous systems. It has proven particularly useful for batch type operations and has reduced over-control problems in both batch and continuous process applications. One virtue is great flexibility; the system can easily be supplemented or modified for special situations. For example, a Cumulative Sum chart, centered at the Acceptable Process Level or some level between the Acceptable Process Level and the Rejectable Process Level, could be added whenever n out of N points exceed the Acceptable Process Level, indicating that the slack in the system has now been used up. A most valuable asset, and one Page also claims for the Cumulative Sum chart, is that there is no cut and dry set of rules that can be applied by rote. It is required that one think about the particular problem he has at hand, and this should lead to a better solution than can be had any other way. Another most important feature of the Acceptance Control system is that the control limits are set up after consideration of the process requirements called for by the specifications. Thus the problem of tight-control can be avoided when such control is not required.

In summary, two new methods of process control have been proposed recently. One, the Cumulative Sum chart (or the Geometric Moving Average chart) is designed to furnish a more powerful tool for detecting the small process shifts that are a serious nuisance when specifications are tight and variability must be held to an absolute minimum. The second, the Acceptance Control chart, is designed to provide a more efficient tool for situations in which normal control or more relaxed control systems are desirable.

Both of these approaches would seem to merit consideration as auxiliary tools in the kit of every Quality Engineer. Indeed, it would not be surprising to see them replace the Shewhart chart completely since each is more efficient in its own area, and the respective areas encompass the whole field.

Illustrative Example

Table I shows a set of twenty averages of four observations per subgroup. The first ten averages come from a random, normal distribution having $\mu = 0$, $\sigma = 2$, $\sigma_{\overline{X}} = 1$. It is assumed that a shift in process level of $+ 3/4 \sigma$, (i.e. $+ 1.5$), takes place between the tenth and eleventh samples so that the second ten averages come from a random, normal distribution having $\mu = 1.5$, $\sigma = 2$, $\sigma_{\overline{X}} = 1$.

The data in Table I are plotted on a Shewhart chart, a Cumulative Sum chart, a Geometric Moving Average chart and an Acceptance Control chart in Figures 1 through 4 respectively. This is done for illustrative purposes only and is not intended as a proof of the superiority of any system. Only one type of process shift, as well as only one particular level of shift, is even considered and only one set of control criteria is looked at for each system. Furthermore, the objectives of the Shewhart, Cumulative Sum and Geometric Moving Average charts differ from those of the Acceptance Control chart. The first three all assume that the process should be held as closely as possible to the nominal value, zero. The Acceptance Control system illustrated here assumes that the specification limits are at $\pm 5\sigma$, (± 10), rather than at the $\pm 3\sigma$, (± 6), natural process limits, or perhaps even tighter ones, for the other systems. The objective of the first three systems is to detect any process shift as quickly as possible. The Acceptance Control chart is designed to detect shifts as large as the Rejectable Process Level (R.P.L.) as quickly as possible while simultaneously trying to avoid process adjustments for shifts as small as the Acceptable Process Level (A.P.L.).

The values plotted on the Shewhart chart, Figure 1, are the subgroup averages, $\overline{X}_t$. The control limits are $0 \pm 3\sigma_{\overline{X}} = \pm 3.0$. All twenty points are plotted because without any supplementary run procedures, the chart does not indicate any shift in process level. It would depend on which run procedure was specified as to when (or whether) the process shift is detected. For example, if $0 \pm 2\sigma_{\overline{X}}$ were set up as warning lines, adjustment might be called for at time 19 since two successive points lie between the warning and action lines.

The values plotted on the Cumulative Sum chart, Figure 2, are the cumulative sums of the deviations of the subgroup averages from the nominal value, $\Sigma(\overline{X}_t - 0)$. These values are listed in Table I. The control limits are a V-shaped mask with the lead distance $d = 5$ and the tangent of half the angle of the V, $\tan \theta = 0.35$.

This particular mask was selected because it has an α risk of about 0.3%, as do the $3\sigma_{\overline{x}}$ limits for the Shewhart chart. Only the first fifteen points are plotted since a point falls under the V-shaped mask when it is used for point 15. Thus, process adjustment would have been called for at this time.

The values plotted on the Geometric Moving chart, Figure 3, are the weighted averages, $Z_t = r\overline{x}_t + (1 - r) Z_{t-1}$. The weighting constant, r, was chosen to be 1/4. These values are also given in Table I. The control limits are $0 \pm 3\sigma_Z$, where $\sigma_Z = \sqrt{\frac{r}{2-r}} \sigma_{\overline{x}}^2$ and they equal ± 1.13. Only the first eighteen points are plotted since the eighteenth point exceeds the limit and calls for a process adjustment.

The values plotted on the Acceptance Control chart, Figure 4, are the subgroup averages $\overline{x}_t$. With the specification limits set at ± 10.0, it is decided to select as the Rejectable Process Level ± 6.0. (This could have been an arbitrary choice, or it could have been done on a basis that a process centered at 6.0 would have less than $2\frac{1}{2}\%$ of its individual items beyond 10.0.) Since the sample size has been specified as four, the Acceptance Control Limit (A.C.L.) = ± 4.35 if we want to limit our β risk to 5%. The Acceptable Process Level would be 1.57 if we want α = 0.3% or 2.70 for an α = 5%. All twenty points are plotted here since none exceed the control limits; nor should they under the above definitions of the control requirements.

TABLE I

Subgroup	$\overline{x}_t$	$\sum(\overline{x}_t - 0)$	$Z_t = r\overline{x}_t + (1-r)Z_{t-1}$; r = 1/4
1	1.6	1.6	0.40
2	0.4	2.0	0.40
3	-1.1	0.9	0.02
4	-0.7	0.2	-0.16
5	1.6	1.8	0.28
6	0.1	1.9	0.24
7	-1.4	0.5	-0.17
8	0.8	1.3	0.07
9	-0.2	1.1	0.00
10	-1.4	-0.3	-0.35
11	0.4	0.1	-0.16
12	2.1	2.2	0.40
13	-0.2	2.0	0.25
14	2.4	4.4	0.79
15	1.9	6.3	1.07
16	1.1	7.4	1.07
17	-0.1	7.3	0.78
18	2.4	9.7	1.18
19	2.9	12.6	1.61
20	1.4	14.0	1.56

$\overline{x}_t$: Average of 4 observations per subgroup taken at time t.

Subgroups 1-10: Random Normal Distribution, $\mu = 0$, $\sigma = 2$, $\sigma_{\overline{x}} = 1$
Subgroups 11-20: Random Normal Distribution, $\mu = 1.5$, $\sigma = 2$, $\sigma_{\overline{x}} = 1$
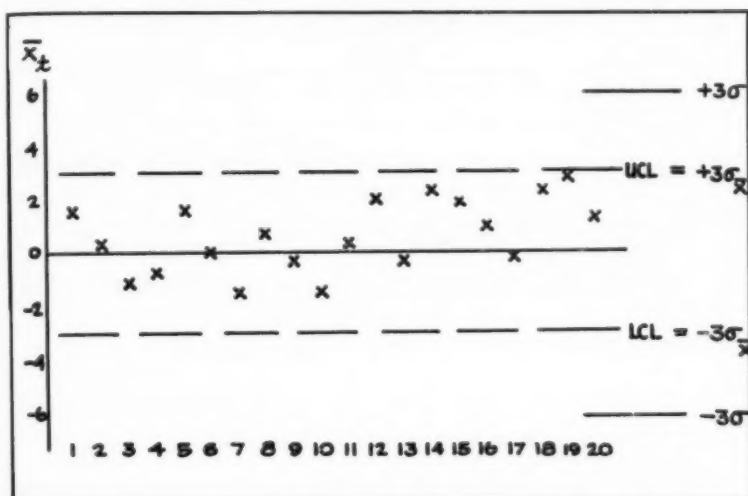
FIGURE 1 — SHEWHART CONTROL CHART
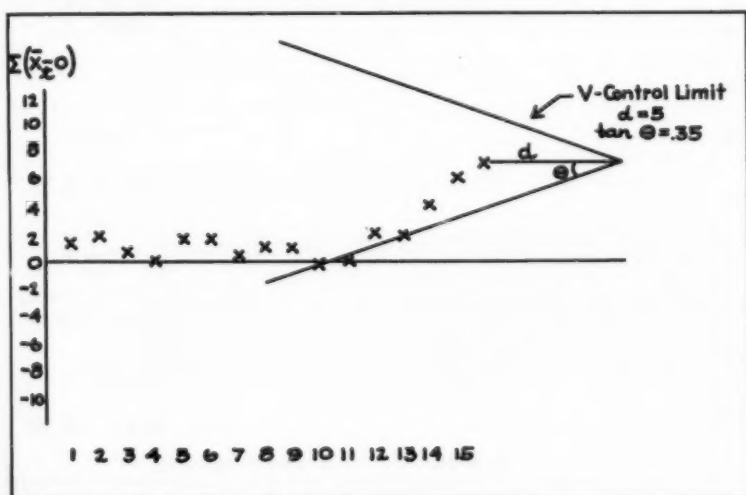
FIGURE 2 — CUMULATIVE SUM CHART
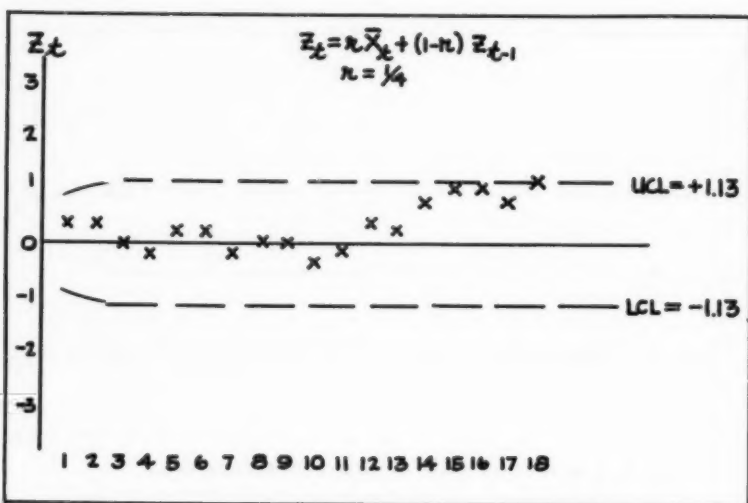
FIGURE 3 — GEOMETRIC MOVING AVERAGE CHART
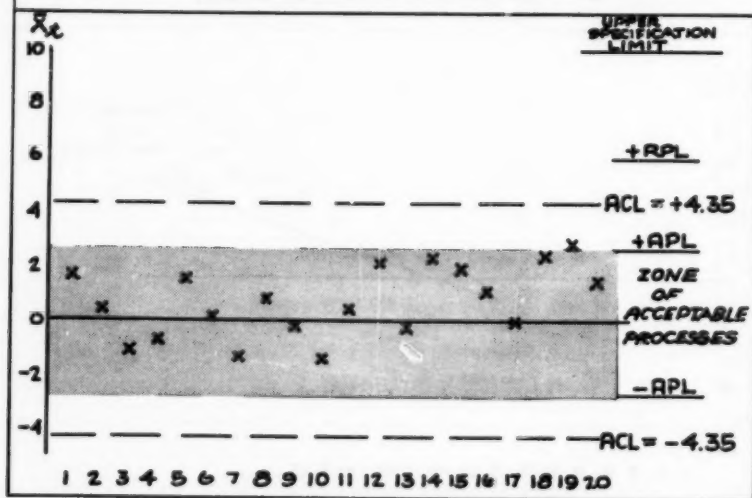
FIGURE 4 — ACCEPTANCE CONTROL CHART

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STATISTICAL METHODS FOR CERAMIC
PROCESS CONTROL AND EXPERIMENT PLANNING*

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Introduction

This paper aims to provide ceramic engineers and technologists with insight into
ways to profit from the use of statistical principles in resolving process control and
development problems. The general principles are reviewed. Their use is demonstrated
with examples from a glass-to-metal seals plant and a laboratory search for optimum
time, temperature and pressure conditions to obtain maximum density in pressure sinter-
ing of alumina.

A number of references to the general quality control literature are cited to sup-
plement the limited number of papers available from the ceramic literature. These gen-
eral papers include specific references to problems of ceramic interest.** As will be
evident to the careful reader, the statistical principles are identical regardless of
the industry to which applied. Their successful use depends on the ingenuity of the us-
er in recognizing the appropriate statistical counterpart to each ceramic problem. It
is emphasized that most quality control procedures can be readily learned and require
little more mathematics than arithmetic. Thus the methods are suited to a one-man plant
technical department as well as to larger plant or staff organisations.

Statistical consideration of a ceramic problem is apt to concern itself most fre-
quently with two properties: (1) the level of a process or product quality (such as the
average moisture content of a mix), and (2) the uniformity of the process or property
(e.g. as measured by differences in moisture content in several samples from different
parts of the mix.) Estimates of level and uniformity based on measurements or judgments
made on small samples of product can be used to predict limits within which additional
sample measurements would fall, or if a process is concerned, limits which will contain
a selected percentage of future measurements as long as the process remains stable. A
greater understanding of variability, how to calculate and judge it, can help ceramists
resolve many recurring problems.

Process Control Uses of Statistics

How should a ceramic process be controlled? It is reasonably clear that the com-
position must first be chosen to meet the final product property specifications. Then,
the raw materials must be selected. The process by which the ware will be made and
fired is the next choice. (This includes conditions for drying, glasing, etc.) If di-
mensional requirements are important, dies or molds must be made to a size to account
for within-process shrinkage. However, it may not be obvious that designing the prod-
uct, choosing the process and inspecting the final product does not represent "control"
nor does it necessarily guarantee production of a single saleable piece. Not only must
the equipment be tuned to the proper settings, but also, if operators are expected to
exercise judgment or adjust the equipment they must be given ways to verify the action
they have taken.

In the press of business, it is not uncommon temporarily to depart from existing
specifications to obtain volume production with the expectation of paying the price in
off-grade ware at a later stage. Lacking complete knowledge, the gamble is that the a-
mount of off-grade ware will be less than the production increase. The successful man-
ager will have built into the process only enough check points (and these at key posi-
tions) to satisfy himself that meaningful in-process specifications are being met along

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  (See Vol. 28, 1959)

** For example, Section 11 of (14) discusses a wide variety of applications in
   the chemical industry and contains hundreds of references. (2) indicates prob-
   lems of interest in research, development, process control and control labor-
   atory areas. Appropriate statistical tools are suggested for each problem.
   Many of these are of direct interest to ceramic engineers. (3) reviews batch
   control and illustrates with control charts and multiple regression procedures.

the way. The heart of the problem, of course, is in picking the places for checking
and in setting the specifications at each point. Fundamental to both of these consid-
erations is the ability to measure* the process at each point, and to know what correc-
tive action must be taken to restore the process to desired values.**

These are the established elements of control. What then do statistical methods
contribute? Very briefly, they provide methods for setting specifications*** and judg-
ing how well a process meets them. One of their concepts asserts that after all "as-
signable" (or identifiable) causes have been removed, only random variation will ex-
ist.**** Limits can be determined which distinguish between the effect of real factors
and this chance or "residual" variation. The statistical techniques can also be used
to determine how well various steps in the process influence final product properties
toward selecting key control points. From a sound theoretical basis, these methods can
describe the frequency and number of samples necessary for economic detection of condi-
tions which would lead to off-grade ware. In inspection of product, decision methods
are available for comparing the number of defects, per cent "chipped," "off-color",
etc., on one day's operation with another. Such measures are valuable in assessing
formulation or process changes.

Statistical Aids in Comparative Tests

In process development, experiments can be planned using statistical "designs"
which permit the simultaneous examination of the effect of many process variables on
intermediate or final product properties. One such example might study the effects of
drying rate, position in the dryer, drying temperature, and initial moisture content on
shrinkage and warpage. Not only do such planned experiments provide pronounced economy
of experimentation, but also they answer questions about the joint effects of the var-
iables that "one-factor-at-a-time" tests do not consider. From such test results mini-
mum risk decisions can be made concerning which variables control in complex situations.
In ceramic formulations, where multicomponent systems are common, "factorial" and other
experimental designs can give quick insight into the response of a property to composi-
tion change much as a phase diagram does.*****

Bulk Material Problems

Raw materials and intermediates used by the ceramist are frequently bulk materials
rather than discrete units. Fortunately, the same general principles of sampling apply
regardless of the way materials may be handled. To characterize a "batch" or "lot" re-
quires a knowledge of variation within the lot and types of stratification that occur.
In addition, the variation of the test method must be considered in specifying a plan
for control or accpetance of bulk materials. The use of experimental designs to obtain
basic design data for such plans is described later in this paper. References (13, 17)
provide additional general information and (5) examples of application in white alumina.

The following examples illustrate the use of statistical methods in two different
ceramic areas - process control and research. As will be evident, statistical proce-
dures can provide the setting for imaginative scientific and engineering identification
and solution of problems. Frequently, the strategies used in bringing about the final
change are more important to the total solution than all the detailed investigation
preceding it.******

* (22) discusses specific gravity measurements in whiteware.

** Reference (4) discusses this in greater detail. (16) describes non-
statistical considerations in Slip House control.

*** See reference (14) for general discussions on quality control including
setting specification and "natural" process tolerances.

**** See reference (9) for details for making control charts for both attri-
butes and variables data. (19) is the original source for control chart
principles including many examples and empirical verification for the
procedures. (12) gives ceramic examples of confidence limits.

***** (11) discusses the application of one such experimental design to white-
ware problems. (6,7,8) offer detailed instructions in the procedures.

****** (15, 18) provide interesting insight into problems in human relations
common to plant problems and studies of this type.

APPLICATIONS IN A GLASS-TO-METAL SEALS PLANT

A sensitive plant management quickly detects deterioration in its product quality from customer complaints, scrap rise or in-process rejections as well as an unfavorable balance sheet. It also recognizes that if its regular control procedures were in force, something more fundamental will be required to correct the situation. In the following example, management of the Latrobe Plant had (1) decided that action was needed, (2) roughly surveyed and identified the product line to be considered, (3) set loss reduction as primary objective, and (4) called for a concerted effort. Two quality control engineers from the central staff were called in to assist the plant product engineering group.

Approach to Introducing S.Q.C.

Following an initial meeting with production and research supervision to review the problem, the stated objectives, and a brief summary of how statistical quality control methods work, a team was formed to conduct a process survey. The seals production foreman, a development engineer and two quality control engineers formed the team. Members of the team were selected in anticipation of skills that would be needed to solve the problem.* A team was chosen rather than individual effort since the quality control engineers were not conversant with the seals process nor the plant procedures. Also, it was expected that the production foreman could arrange for special samples, inspection, modification of operating procedures, etc., as needed. The research engineer provided technical know-how concerning the product design, raw material properties and significant process controls.

The process survey had 3 purposes, to:

(1) establish the existing process and its controls;
(2) determine the quality control needs of the process;
(3) identify the present quality level, factors contributing to it, and to measure the state of statistical control present.

The initial survey was limited to raw material receiving, mixing, pressing, sintering, inspection, packaging and shipping. (See Figure 1).

An analysis of inspection losses pinpointed the areas suggesting most profitable study. Further examination showed that a few production items accounted for a major part of the total loss. To maximize team effectiveness and produce the most results in the brief time allocated, the team effort was directed first toward these few high loss items. The program would be extended to the other areas and items as the need arose. The following discussion covers many of the important areas in detail.

Raw Material

The manufacture of glass seals consists primarily of assembling various components such as leads, glass beads, eyelets, headers, etc., by fusion and/or welding into a finished unit. (See Figure 2.)

* See (1) for a more detailed discussion of Carborundum's team approaches.
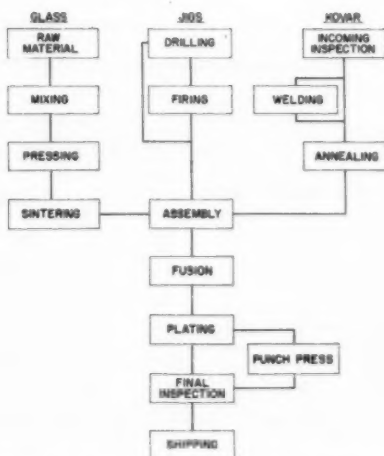
Figure 1—GLASS-TO-METAL SEALS PROCESS FLOW SHEET

GLASS BEAD

$\oplus$

☒ L

L = LENGTH (CONTROLLED DIMENSION)

ASSEMBLY
(CROSS SECTION)

— LEAD
— HEADER
— GLASS BEAD
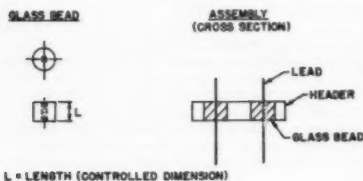
The team set out to answer the question, "How well were the components supplied by our vendors conforming to blueprint specifications?" Random samples were selected and measurements were taken relative to the specifications. The distribution of the length of 278 leads randomly selected from stock is shown in Figure 3*. Table I illustrates the calculation to compare performance with specifications.

Figure 2-GLASS-TO-METAL SEALING UNIT

* Note how dramatically these simple graphs demonstrate vendor performance. This makes them valuable in discussing quality improvement. (The nominal value is 1.000+ reading shown, i.e., 1.053 etc.)
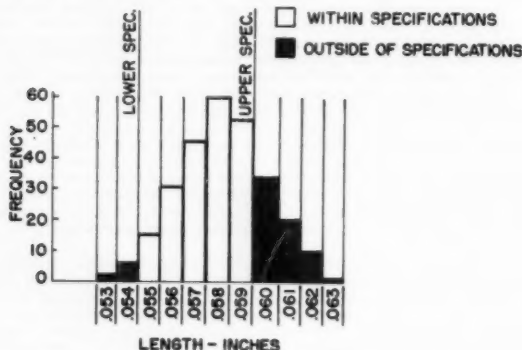
Figure 3—HISTOGRAM SHOWING LENGTH DISTRIBUTION OF 278 LEADS

TABLE I - COMPUTATION OF AVERAGE AND STANDARD DEVIATION

(Length of 278 Leads Randomly Selected from Stock)

Lead Length (inch)*	Frequency	Deviations		
(x)	(f)	(u)	(fu)	(fu^2)
.053	2	-5	-10	50
.054	6	-4	-24	96
.055	15	-3	-45	135
.056	31	-2	-62	124
.057	46	-1	-46	46
.058=(A)	60	0	0	0
.059	53	+1	+53	53
.060	34	+2	+68	136
.061	20	+3	+60	180
.062	10	+4	+40	144
.063	1	+5	+25	25

Formulas:

$$\bar{x} = A + c(\Sigma fu / \Sigma f)$$

$$\sigma_x = c\sqrt{[(\Sigma f)(\Sigma fu^2) - (\Sigma fu)^2]}/\Sigma f$$

Notation:

$\bar{x}$ = average
σ_x = standard deviation
c = class interval = .001
A = arbitrary midpoint
u = deviation in cells from A
$\quad (x = A + cu)$

$c = .001 \quad \Sigma f = 278 \qquad \Sigma fu = 39 \quad \Sigma fu^2 = 989$

Calculations:

$\bar{x} = .058 + (.001)(39)/278 = \qquad .0581"$

$\sigma_x = .001\sqrt{[(278)(989)-(39)^2]}/278 = .00188"$

Per Cent of Parts Beyond Specs (Normal Curve Theory**)

(a) Below lower spec: (.054 - .0581)/.00188 = -2.18 or 1.5% below 1.054"
(b) Above upper spec: (.059 - .0581)/.00188 = +0.48 or 31.6% above 1.059"

where (spec - $\bar{x}$)/σ_x = z   compare z with Normal Curve Area**
*Add 1.000 in. to get actual values.   ** See reference (9).

Toward improving incoming inspection, operating characteristic ("o.c.") curves such as shown in Figure 4 were prepared to show plant inspectors the probability of accepting lots containing a certain percentage of nonspecification parts for a given sample size and acceptance number. Note that if protection is wanted against accepting lots containing 5% defective parts, the plan offering the greatest protection is the one which calls for a sample size of 75 and acceptance number of 0.* Table II shows that the greatest _incremental_ increase in protection occurs when going from a sample size of 25 to a size of 50. Also that a sample size of 25 and acceptance number of 0 offers the same protection as a plan calling for a sample of 50 and acceptance number of 1.
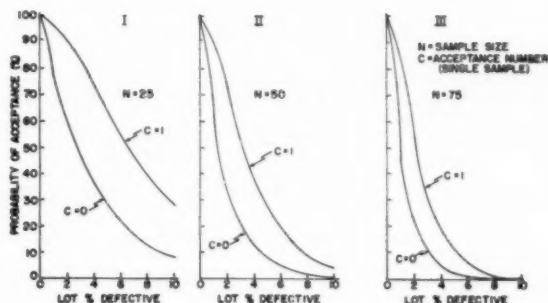
Figure 4—COMPARISON OF OPERATING CHARACTERISTIC CURVES FOR DIFFERENT SAMPLE SIZE — SAME ACCEPTANCE NUMBERS

TABLE II - CHARACTERISTICS OF SAMPLING PLANS

OC Curve	Sample Size	Acceptance Number	Probability (%) of Accepting Lots 5% Defective
I	25	0	28
		1	65
II	50	0	8
		1	28
III	75	0	2
		1	12

Pressing

Another study involved the control of physical dimensions of pressed small glass beads. (These glass beads are an essential part of glass-to-metal sealing units used in the manufacture of transistor assemblies. See Figure 2.)

The goal was to produce uniform length beads as too much glass or not enough glass resulted in a defective seal. Green length and green weight were chosen for control. (See Figure 5.)

    * "acceptance number = 0" means, accept the lot as adequate quality if
      no defective pieces are found in the sample. If 1 or more are found
      reject the lot.
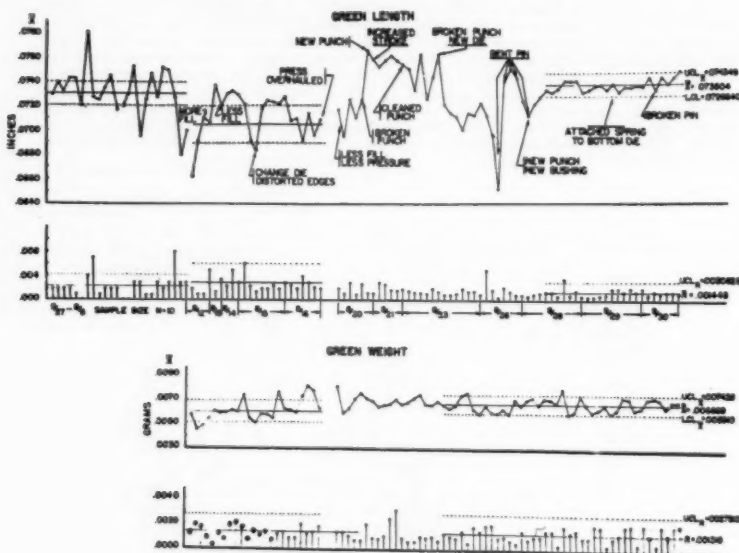
Figure 5- CONTROL CHARTS FOR GREEN LENGTH & GREEN WEIGHT-GLASS BEAD

    The average, range, and control limits were computed for samples of 10 measurements for green length from existing data. (May 27 to August 5.) It was evident that the process was out of control for length. There were no back data available for green weight.

    On August 12, random samples of 5 beads were taken directly from production and checked for green length and green weight. New control limits were calculated (August 12 to August 16.) Points representing a change in the process were labeled and attempts made to assign causes for lack of control.

    The chart indicated that green length was still out of control, and that the green weight was steadily increasing and also out of control. The team decided that the press was in bad condition and that repair was imperative before adjustments could effectively be made to bring the process under statistical control. The press was sent to the maintenance shop to be overhauled. On August 20, the press was put back into operation but the level of the process was as variable and out of control as ever.

    Close examination of the charts showed that directly after overhauling the press (August 20 to August 26), two significant changes had occurred. A decrease in variation from bead to bead was evident from the reduction in the range. However, the frequency of punch breaking and bending seemed greater. A closer look at the press showed that a bottom bushing (which permitted excessive play in the die, thus causing the punch to bend and break) was missing. This condition was unknown to anyone and it is doubtful if it would have been discovered without the aid of the control chart. The bushing was replaced on August 28 and the process was brought under statistical control. The reject rate was reduced from 18% to 2%.

Jigs
    Discussion so far has been limited to the control of defects attributed to raw material and process variables. However, many of the defects could also be attributed to

equipment design. In particular, an analysis of scrap causes revealed that approximately 75% of the total scrap was due to the jigs.

At a meeting of the team (with manufacturing engineering) it was decided to concentrate on improving the jig design.

Figure 6 depicts the results. The particular part chosen for the study was running at a 38% defect level prior to the change in jig design. With the adoption of an improved, more efficient jig, the scrap level was reduced to 7%. As a result of this improved quality, 100% inspection gave way to sampling inspection with an additional saving in inspection cost and scrap.
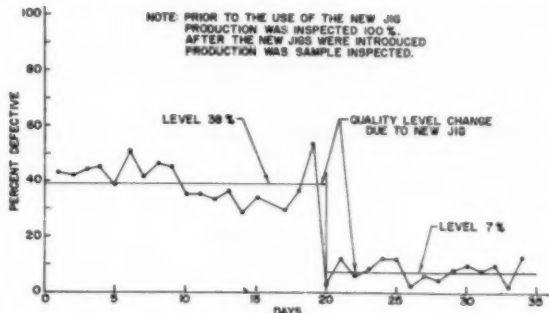
Figure 6-PERCENT DEFECTIVE CHART

The contribution of the team to the solution of the problem was mainly to call attention to the cause of the difficulty. The modification which the redesign entailed required many hours of work by the engineering group.

Final Inspection
Visual inspection was principally used to inspect the final parts. This method relied heavily on the use of judgment by the inspectors in accepting or rejecting finished lots of seals ready for shipment. To test the effectiveness of this inspection, the team submitted lots of finished parts which had been inspected by the day shift inspectors to the night shift inspectors for reinspection, and vice versa. To eliminate the possibility of any bias in the checks, the inspection department was not alerted to what was being done.

The results showed that under the system being used, it was impossible to determine a realistic outgoing quality level on the item under investigation because no two inspectors inspected alike. It was not uncommon for one inspector to reject material accepted by another inspector.

This situation called for a complete review of the classification of defects. Customers were visited to obtain concise definitions of the quality characteristics required. It is interesting to note that in some cases final inspection was "too tight" on certain quality characteristics of the finished part. Consequently, parts that otherwise were considered good and usable by the customer, were being rejected by inspection. Based upon the response from customers, the definitions of quality defects were revised and new standards set up. The retraining of inspectors to the use of the standards and new definitions of quality defects led to immediate improvement and additional loss reduction, the objective of the work.

In summary, this example has shown the effectiveness of modern statistical quality control principles when applied in an orderly, systematic investigation of ceramic processing problems. These methods afford economically controlled material from entrance to exit. Quantitative, rather that qualitative judgment makes routine comparisons more discriminating even though attributes are being controlled. Graphical devices, such as

control charts, histograms, and sampling table consequences can instill quality minded-
ness in the operator. The team approach can make the most of many people's experience
while directing concerted effort to the most pressing problem. Only the most recalci-
trant can be opposed to the recommendation for process improvement which his work has
helped to prove essential. These brief examples may suggest that results are always
forthcoming rapidly. In several instances, solutions were only found after endless
hours of engineering work by other plant personnel.

Another problem lending itself to systematic examination, is that of assessing
what combination of levels of each of a number of process factors will produce maximum
yield (or minimum cost; etc.). The next example discusses these approaches.

LABORATORY SEARCH FOR MAXIMUM DENSITY

During research into the mechanism underlying pressure sintering it was of inter-
est to find combinations of time, temperature and pressure which would lead to maximum
density.* The theoretical pressed density for the alumina to be studied was 3.98 g/cc.

Selecting the Model and Experimental Design

Preliminary work suggested the ranges shown in Table III within which further ex-
periments should be performed. Lacking more complete knowledge, a second order math-
ematical model was chosen to represent the influence of each of the variables on
pressed density. The initial model expressing density as a function of pressure, tem-
perature and time was:

$$d = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + \qquad (1)$$

$$b_{33} x_3^2 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3$$

where x_1 = (pressure - 1600) /370   (2)
x_2 = (temperature - 1450) /150
x_3 = (time - 20.0) /6
d = pressed density (g/cc)

The scaling of equation (2) was designed to produce equal changes in density for a 1
unit change in each x.

TABLE III - RANGE OF EXPERIMENTAL VARIABLES

Pressure (psi)	Temperature (°C)	Time (min.)
1000	1205	10.2
2200	1695	29.8

Since the objectives included learning as much as possible about the time-tempera-
ture-pressure system, an experimental design was chosen which permitted "mapping the
surface" of the system.** The properties of the design allowed the experimental work
to be carried out on 3 separate days ("groups" I, II, and III) while still retaining
the ability to separately assess the influence of each of the variables independently.
Also, each group had a built-in measure of experimental error for control. Finally,
from the overall design a test could be made later to judge whether the model chosen
was adequate. Table IV shows the experiments performed and the results.

* Experimental details and a discussion of their significance has been
  reported separately in a paper by the researchers, G. Mangsen,
  W. Lambertson, and B. Best.: Journal American Ceramic Society
  Vol. 43, No. 2, February 1960 p. 55 - 59, "Hot Pressing of Aluminum
  Oxide".

** See (11) for another application in studying whitewares. Also
   (6, 7, 8, 10, 20) for other statistical designs.

TABLE IV - TEST SEQUENCE AND RESULTS

Group No.	Run No.	Design Units			pressure (psi)	temp. (°C)	time (min.)	Fired Density (g/cc)
		x_1	x_2	x_3				
I	1	+1	-1	+1	1970	1300	26	2.17
	2	+1	+1	-1	1970	1600	14	3.69
	3	0	0	0	1600	1450	20	2.92
	4	-1	+1	+1	1230	1600	26	3.53
	5	-1	-1	-1	1230	1300	14	1.77
	6	0	0	0	1600	1450	20	2.92
II	7	-1	-1	+1	1230	1300	26	1.77
	8	0	0	0	1600	1450	20	2.88
	9	-1	+1	-1	1230	1600	14	3.37
	10	0	0	0	1600	1450	20	2.91
	11	+1	+1	+1	1970	1600	26	3.83
	12	+1	-1	-1	1970	1300	14	2.10
III	13	1.63	0	0	2200	1450	20	3.05
	14	0	0	0	1600	1450	20	2.92
	15	-1.63	0	0	1000	1450	20	2.35
	16	0	0	1.63	1600	1450	29.8	3.04
	17	0	-1.63	0	1600	1205	20	1.66
	18	0	0	0	1600	1450	20	2.87
	19	0	1.63	0	1600	1695	20	3.86
	20	0	0	-1.63	1600	1450	10.2	2.61

Data Analysis and Interpretation

A visual examination of these results shown in Figure 7 (summarized in Table V)
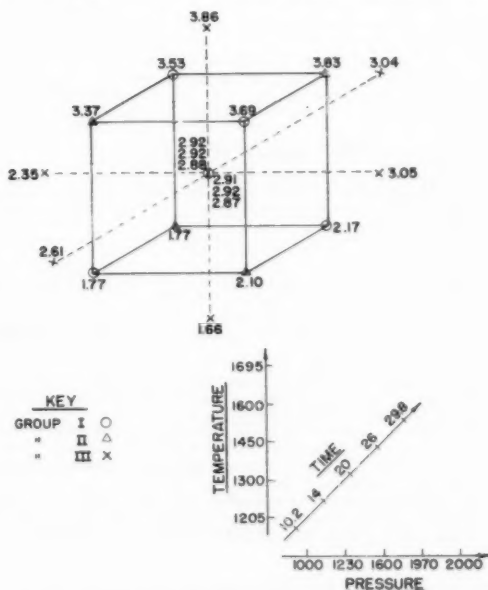
Figure 7- EXPERIMENTAL RESULTS- DENSITY AS A FUNCTION
OF TIME, TEMPERATURE AND PRESSURE

TABLE V - CHANGE IN DENSITY - ESTIMATES OF THE EFFECT OF VARIABLES

| Variable | Change in Density | | Units |
	Per Design Unit (g/cc/unit)	Per Experimental Unit	
time	.018 - .075	.30 - 1.25	g/cc/100 min.
temperature	.85	.57	g/cc/100° C.
pressure	.17	.46	g/cc/1000 psi

suggested that time had slight effect at the low levels of temperature and pressure but about two times more pronounced effect at higher levels. Even so, temperature seemed to be about eighteen times more influential than time. The influence of pressure on density was intermediate between temperature and time. Table VI shows these results in more complete form with their 95% confidence limits.*

TABLE VI - COEFFICIENTS AND THEIR ERRORS*

Symbol	Pressure (x_1)	Temperature (x_2)	Time (x_3)	Value of Slope	Confidence Limits
b_0				2.90	+ .027***
b_1	x			.187	$\mp$ .018
b_2		x		.765	$\mp$ .018
b_3			x	.080	$\mp$ .018
b_{12}	x	x		-.014	$\mp$ .024
b_{13}	x		x	.006	$\mp$ .024
b_{23}		x	x	.029	$\mp$ .024
b_{11}	**			-.068	$\mp$ .018
b_{22}		**		-.046	$\mp$ .018
b_{33}			**	-.021	$\mp$ .018

    * Slopes have units "g/cc per design unit". To convert to experimental units divide by 370, 150, and 6 respectively for pressure, temperature, and time. (See equation (2).)

    ** Coefficients of x_i -squared; x_1^2, x_2^2, x_3^2.

    *** The 95% confidence limits shown are based on the 4 degrees of freedom of the experimental error estimated from the replicated center point.

Table VII provides an alternative way to assess the significance of the various coefficients. From analysis of these tables, it was concluded that:

    (a) in the model, both the first order (x_i) and second order (x_i^2) terms were needed.

    (b) the interaction terms $(x_i x_j)$ had small effect.

    (c) no substantial difference occurred from groups I and II to III. This meant that any changes in apparatus, procedure or material had no influence on the results.

    (d) experimental control appeared excellent - the measure of experimental error** in groups I and II was not different from that in group III, and also compared well with a previous estimate based on 7 separate runs.

    (e) a better model should be sought. Although more than 99% of the density variation had been accounted for, based on this experimental error, the "lack of fit" term was significant.

    * Values are judged _statistically_ significant if their ranges do not include zero. Hence, $\overline{b_{23}}$(.029 ±.024) is significant but b_{12}(-.014 ±.024) is not.

    ** (how well repeated runs made under one set of conditions agreed - 0, 0, 0 design units were used here)

TABLE VII - ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sums of Squares	Mean Squares
Constant	1	158.0344	
First Order	3	8.3592	2.786*
Second Order	6	.0945	.0157*
Blocks	1	.0030	.0030
Residual	9	.1082	
Lack of Fit	(5)	(.1059)	.0212*
Experimental Error	(4)	(.0023)	.00058
Total	20	166.5993	

* significant at better than 0.5%; i.e., chance occurrence of exceeding the "critical mean squares" based on an experimental error of .00058 is only 5 in 1000.

Clues for a Better Model

To more fully understand the implications of these results a "canonical analysis" was made of the equation. This procedure simplified equation (1) by rotating and translating its axes. The resultant equation

$$d - 7.66 = -.071Y_1^2 - .049Y_2^2 - .0147Y_3^2 \qquad (3)$$

$$\text{where } Y_1 = -.929(x_1 - .672) - .338(x_2 - 11.28) + .157(x_3 - 9.58)$$

$$Y_2 = .371(\quad " \quad) - .842(\quad " \quad) + .390(\quad " \quad) \quad (4)$$

$$Y_3 = -.001(\quad " \quad) + .421(\quad " \quad) + .907(\quad " \quad)$$

defines a set of ellipsoids. A comparison of the coefficients of Y_1 with their 95% confidence limits $\pm$ .0184 suggests that the effect of Y_3 can be ignored for purposes of further examination. Thus, equation (3) reduces to a series of ellipses* to represent the time-temperature-pressure system.

In the course of finding equation (3), equation (1) with appropriate coefficients of Table VI was differentiated partially with respect to x_1, x_2, and x_3, the three resulting equations set equal to zero and simultaneously solved for the maximum. A maximum density of 7.66 g/cc was indicated for $x_1 = 0.672$, $x_2 = 11.28$, and $x_3 = 9.58$ (design units for pressure, temperature and time, respectively.) This was in contrast to the maximum theoretical density of 3.98 g/cc. Since the polynomial model chosen had its coefficients determined in the experimental space of interest, its results should not be extrapolated too far beyond it.** Table VIII shows the path of steepest ascent from the center of the design toward theoretical density based on the "first order" terms only and indicated that close approximation to theoretical density could be achieved within the space explored. Figure 8 shows typical constant density contours calculated from the full model for one selected time (26 min.). The agreement with the experimental points is remarkably good. Examination of similar diagrams for other time values further shows that its effect on density was slight in these pressure-temperature ranges.

The procedure described is only one of the many ways that experimental designs can be used to help experimenters. In this example, the design and accompanying statistical analysis aided the experimenter to achieve quantified, meaningful results with a

* The system has in effect been reduced to 2 variables, $d = f(Y_1, Y_2)$. However, Y_1 and Y_2 are functions of x_1, x_2, x_3 (or pressure, temperature and time.) This means that 2 new variables can be found which more fundamentally represent the physical effect of pressure, temperature and time. The coefficients of equation (4) should aid the experimenter in selecting such variables.

** A better "fitting" model could be expected to predict a maximum value closer to 3.98 g/cc.

TABLE VIII - PATH OF STEEPEST ASCENT

Level of Variables*

Pressure (x_1)		Temperature (x_2)		Time (x_3)		Calculated Density
E. u.	D. u.	E. u.	D. u.	E. u.	D. u.	g/cc
1600	.0	1450	0	20.0	0	2.90
1627	.073	1495	0.3	20.2	.032	3.15
1654	.147	1540	0.6	20.4	.063	3.39**
1681	.220	1585	0.9	20.6	.094	3.63
1709	.293	1630	1.2	20.8	.126	3.87
1736	.367	1675	1.5	21.0	.158	4.11**

* E. u. = Experimental units, D. u. = Design units.

** The full second order equation predicted 3.41 and 4.02 respectively for the 3.39 and 4.11 g/cc shown.
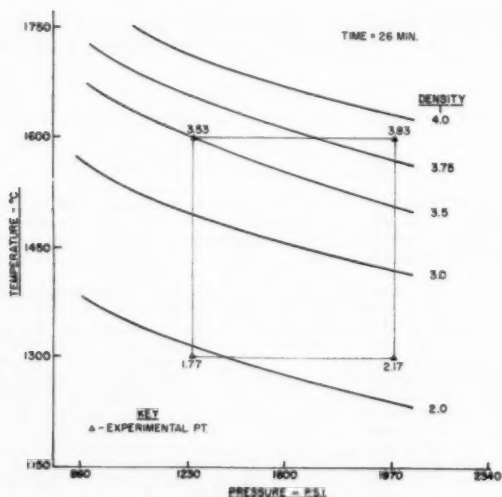
Figure 8-CALCULATED DENSITY CONTOURS

minimum of experimentation. In addition, the derived mathematical model permitted "desk-side" examination and study thus stimulating modification and improvement of the model.* In the final test, the organization of an experimental program has been optimum when it maximizes the inventiveness of the scientist in formulating and testing his theories-- mathematics provides insight, generality and extension.

ACKNOWLEDGMENT

* An improved model is presently under test by the experimenters.

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AN INTRODUCTION TO CUMULATIVE SUM CHARTS

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Last year an article in the Chemical and Engineering News[1] indicated Atlas Powder Company's successful application of a new statistical quality control approach. This new approach centers around the use of the cumulative sum or CS chart. This chart was originally devised by Page[6,8] and further expounded upon by Barnard[2] during the last six years.

The purpose of this article is to first show that cumulative sums are merely a logical extension of regular charting techniques and then to describe the actual use of CS charts in practical application.

In discussing applications, two major advantages will be stressed:

1) Quicker detection power when a true shift from control occurs.

2) The ability to use a look-and-see approach that allows the application of graphical estimation techniques.

It will initially be assumed that the data (x measurements) are equally spaced and are independently and normally distributed with constant system noise or variance σ^2, and that detection or estimation of location parameter shifts is a primary interest.

Control chart strategy will be considered first and then Page's extension of regular control charts to the cumulative sum concept will be shown.

Strategy

An important general characteristic of any control chart is the average run lengths associated with the scheme. When the true process level remains constant, the average run length, L, of the scheme is the expected number of samples recorded before action is indicated. Now L is a function of the true process level relative to the control level. The criterion for selection of one control scheme over another should be either

$$\text{Max } L_0 \text{ for fixed } L_1, \text{ or}$$

$$\text{Min } L_1 \text{ for fixed } L_0$$

The average run length is L_0 when the process level is at the control point and is L_1 when the process has shifted from control by some magnitude λ. L_0 and L_1 are functionally related (sometimes in a complicated manner) to the usual Type I and Type II errors.

It has been shown[7] that for fixed L_0, L_1 can be reduced on the regular Shewhart[9] chart by the addition of warning lines such as is shown in Figure 1. This extension of a regular control chart has not only the usual action lines but also has warning lines between the action lines and the control point. The decision rules are as follows:

1) If a single point is outside an action line, then action is indicated.

2) If two consecutive points are between the action and warning lines and on the same side of the control point,

FIGURE 1

SHEWHART CONTROL CHART

WARNING LINE

PROCESS CONTROL LEVEL

TIME ⟶

FIGURE 2

CS CHART FOR SCORES
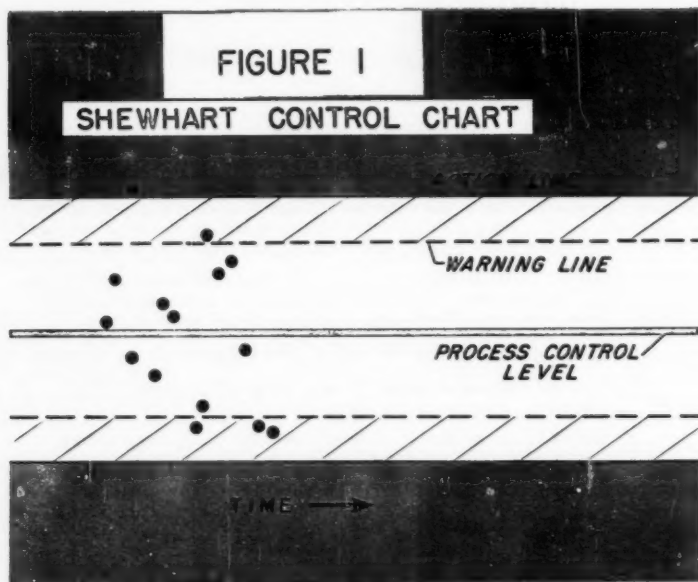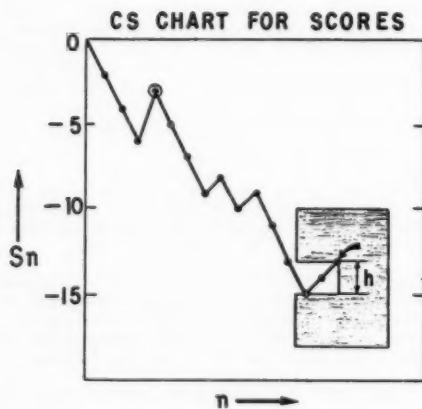
then action is again indicated.

3) If other sequences of points occur no action is taken on the system.

The Transition

This regular control chart can now be reformulated into a cumulative sum chart. In Table I, the different zones are given numerical scores. A score is applied to each of the points on a regular chart, based upon the zone in which the point falls. A series of such scores, y_i, is also shown in Table I. These scores are recorded and a cumulative sum is formed by adding each value to the last previous sum of values

$$S_n = \sum_{i=1}^{n} y_i .$$

It is assumed no action has been taken since y_0. The CS decision rule consists of taking action when

$$S_n - \underset{0 \leq i \leq n}{\text{Min } S_i} \leq h .$$

For this particular scoring system $h = 2$. In the example shown, in Figure 2, the points (S_n, n) are plotted on a CS chart and a special mask constructed with a vertical slot of 2 units. The mask may be applied by placing the upper left corner of the mask on the last point, S_n. The action condition, h, will only be satisfied when (Min S_i) either touches or falls beneath the mask.

Due to our transition method this CS procedure is now a one-sided test. However, it does show the degenerate case of cumulative sums in which only individual samples and two consecutive samples are considered. Although this CS procedure offers no run length benefits over the previous regular chart, it does show that a CS procedure can consider consecutive runs of points through a single action rule.

Additional zones could be established on the Shewhart chart which would allow consideration of more complicated cases of runs up to k consecutive points. These could in turn be transformed into a CS procedure. Although the average run length should be improved by such techniques it now becomes obvious that a CS chart of the original x_i data should offer further benefits. There are now no a priori restrictions on the number of consecutive points that can be considered and the original x_i data should offer more information than would the y_i scores.

CS Control Concepts

The one-sided CS chart for original data has physical characteristics similar to the discrete case for scores. Optimum average run length properties for CS charts occur[4] when

$$S_n = \sum_{i=1}^{n} (x_i - k)$$

$$k = \frac{u_0 + u_1}{2}$$

Here u_0 is the control level and u_1, the desired rejection level. Once again, as in the discrete case, the action criterion becomes

FIGURE 3
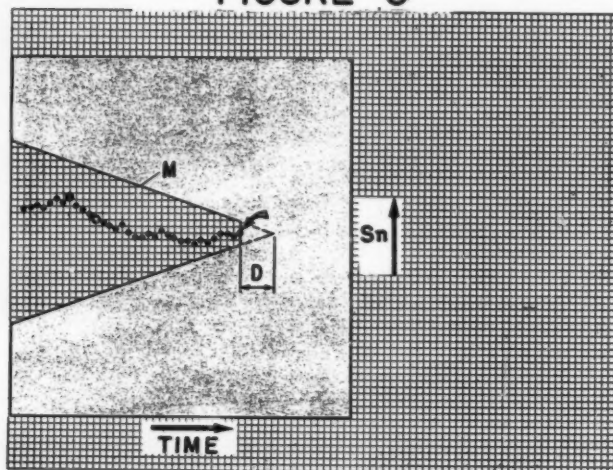
FIGURE 4
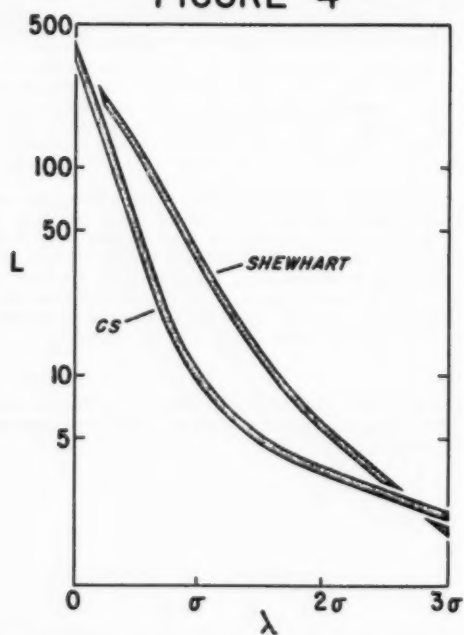
$$S_n - \text{Min } S_i \leq h$$

$$0 \leq i \leq n$$

and a mask of the same general form as previously shown for a one-sided test in Figure 2 could be used for taking action. A disuccion by Ewan and Kemp[4] of the one-sided test, complete with tables and formulaes, appears in _Biometrika_.

The two-sided CS test can now be discussed since the relationship between regular and CS charts has been indicated. This is the more important case because many charting procedures in processing industries require two-sided control.

In this case S_n is defined as

$$S_n = \sum_{i=1}^{n} (x_i - k) \qquad k = u_0.$$

Action is now based on a V-shaped mask. The vertex of the V points horizontally forward when placed on the chart. Note in Figure 3 that there is a horizontal distance D which has not been cut from the mask. Therefore, the important parameters of this mask are the distance D and the slope M. The point of the mask indicated by the arrow is placed at the last cumulative sum and past data is reviewed. As with earlier masks no action is taken if all points since the last action point are visible. The action signal results when some S_i in this interval either touches or falls behind the mask.

Two points in Figure 3 have been illustrated as larger dots. When the mask was placed on the second of these points, action was indicated by the first point falling behind the mask. Therefore, when reviewing future data, only points after this second larger point are considered. This procedure assumes that corrective action was taken at the time of the action signal and system response lag was trivial.

Masks may be constructed by two techniques. One solution requires a "cut-and-try" approach whereby D and M are selected by analysis of past CS charts. In practice a series of CS charts are prepared. Known process operational changes and product quality information are also noted on these charts. A process engineer familiar with the system is given the task of preparing a "best" V-shaped mask. He is instructed to select the final mask so that the cumulative sums remain within the V during periods when the system appears to be operating in a satisfactory manner. However, during periods when system changes were known to have occurred or unsatisfactory quality existed, his mask should be designed to detect these situations quickly. The other approach requires approximations to the solutions of the random walk with absorbing barriers on the edge of the V. These solutions allow the determination of D and M based on fixing L_0, L_1, plus the magnitude of process shift that must be detected. Goldsmith and Whitfield[5] present charts for use in the selection of D and M, and show that the run lengths of these CS procedures are not seriously affected by first-order serial correlations except for negative correlations near -1. This information is very important, since experience has indicated that many industrial systems exhibit some degree of serial correlations.

An actual example can best show the advantages of a CS approach. Both V-mask construction techniques were applied. The solutions to the two schemes are shown in Table 2. In the mathematical solution L_0 was selected to correspond to the same average run length as the previous Shewhart control chart in use. The "cut-and-try" method showed good

agreement between the two approaches.

The average run lengths for this example are shown in Figure 4. All examples are two-sided (based on x data). This clearly shows the improved average run length characteristics associated with CS techniques for process shifts of less than about 3σ from control.

Comparisons of extended amounts of data on CS charts before and after application of V-mask procedures has dramatically reflected the resulting improvement in detection power that is indicated in Figure 4.

In some cases these CS techniques have actually been set up in the process control room. The operator responsible for the system actually plots information and makes decisions based on the use of a V-mask. Such applications have been very successful, since the CS chart itself supplies additional information to the operator. He can now visually review past data from the chart and develop a better feel for the process system. In this way his interest in the control plan is stimulated. This additional information comes from the fact that the CS charts have a considerable amount of visual estimation power built into them.

A "Look-and-See" Approach

Charting techniques will now be discussed from the more general viewpoint that such charts can be used not only with control procedures, but also estimation procedures. Recall the cumulative sum was defined as

$$S_n = \sum_{i=1}^{n} (x_i - k)$$

During a period when the process is operating at some level, u_j, it is noted that from the original assumptions

$$x_{ij} \quad N(u_j, \sigma^2) \qquad \text{and}$$

$$E(S_n) = \sum_{i=1}^{n} E(x_{ij} - k) = n(u_j - k) = n\lambda_j.$$

Therefore, when the true process level is different from control, the CS points should tend to form a slope of approximately λ_j, the true difference from control. Now n points along the horizontal time axis will create a displacement on the vertical CS axis of approximately $n\lambda$, whereas on a regular chart the vertical displacement is only of magnitude λ. It is obvious that the scale factor of the vertical axis must be compressed if a large number of points are to remain on the chart. A scale factor of approximately 2 to 3 sigma per observation has been found to give satisfactory results, permitting most CS data to remain on the chart. Such a scale factor has also been found to supply additional information. Basically, this information results from the fact that the scale factor compresses most of the relative system noise between points into a zone of plus or minus one unit on the vertical axis yet does not seriously affect the magnification factor $n\lambda$.

The result of this scale factor is shown in Figure 5. Random normal deviates[3] with distribution $N(0,4)$ were sampled from tables. The first points have an input of $+1\sigma$, the second 20 an input of 0, and the third 20 an input of -2σ. These inputs are analogous to process levels of an industrial system. Figure 5 represents a typical picture that was exhibited when 25 such sets of data were plotted on CS charts. The regular control chart, with 3 sigma limits centered about zero, is shown first. It obviously supplies a minimum of information and does not readily lend

FIGURE 5
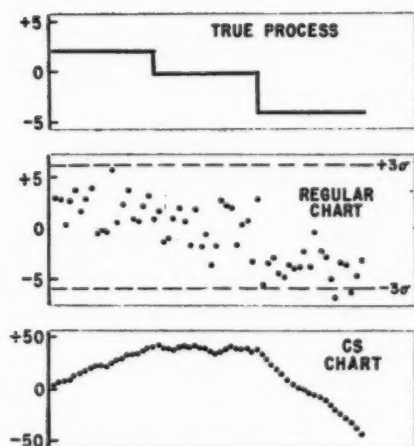
FIGURE 6
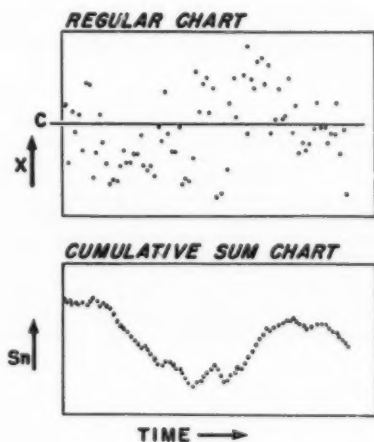
itself to estimation of process shifts.

Now consider the CS chart. Due to the proper selection of scale factor the cumulative sum is restricted to a reasonable area - yet the three process levels now become distinct. The process noise has been largely masked, resulting in a visual tracking of the true system level. When the process is operating above control the points form a positive slope, when on control the points form a nearly horizontal pattern, and when below control they create a negative slope illusion

Note that in this example one can observe the same type of visual impact the CS charts created for the operator on the system when he was using the CS chart as a control procedure. Therefore, the CS chart can also be used with a "look-and-see" approach to general process study or control.

Assume the data shown in Figure 5 represented process data and that neither magnitudes nor time locations of process shifts were known. It is now apparent that estimates of both process properties can be made from the CS chart. This example indicates that time location estimates of process shifts are quite precise when data is CS plotted. Indeed the 20 sets of random deviates show that the CS chart has excellent detection power relative to point of process shift.

The magnitude of the process level relative to the standard, k, can be estimated by evaluating the cumulative sums between two estimated shift points, n and n-r. This estimate of λ (n,r) can be calculated from

$$\lambda(n,r) \doteq \frac{S_n - S_{n-r}}{r}$$

Since the CS chart can show good estimation of the point of process changes, the estimates of λ should be relatively unbiased.

Figure 6 shows an example of actual process data. The data is plotted on both regular and CS charts. Whereas the regular chart only suggests the occurrence of several process shifts, the CS chart clearly indicates the existence of a number of process shifts. Such charts can be used to advantage in studying past data on process systems.

Conclusions

It has been shown that the CS techniques offer the possibility of not only improved control but also graphical estimation procedures. This supplies the quality control engineer in any industry with valuable new techniques. Wholesale replacement of regular charting techniques is not proposed. Rather, selected application of CS charting techniques in conjunction with current methods should result in process improvement. CS techniques are new and further sampling studies and mathematical treatment is necessary to allow their full exploitation.

Actual CS plotting of your own data is a simple way for one to develop an intuitive feel for the possible benefits. If this article results in the reader's taking this initial step, then its purpose has been fulfilled.

Table I

Zone	Score (y)
	3
	1
	-2

i	y_i	S_i
1	-2	-2
2	-2	-4
3	-2	-6
4	3	-3
5	-2	-5
6	-2	-7
7	-2	-9
8	1	-8
9	-2	-10
10	1	-9
11	-2	-11
12	-2	-13
13	-2	-15
14	1	-14
15	1	-13

Table II

CONTROL MASK EXAMPLE

"Cut-and-Try"	Mathematical
M = 1.9	M = 1.75
D = 5.2	D = 5.00

1) Anonymous (1960). Cumulative Sum Chart - New Quality Control Tool. Chemical and Engineering News, March 21, 50-51 and cover.

2) Barnard, G. A. (1959). Control Charts and Stochastic Processes. J. R. Stat. Soc. B, 21, 239-271.

3) Dixon and Massey (1951). Introduction to Statistical Analysis, New York, McGraw-Hill.

4) Ewan and Kemp (1960). Sampling Inspection of Continuous Processes with No Autocorrelation Between Successive Results, Biometrika, 47, 363-380.

5) Goldsmith and Whitfield (1961). Average Run Lengths in Cumulative Chart Quality Control Schemes. Technometrics, February.

6) Page, E. S. (1954). Continuous Inspection Schemes, Biometrika, 14, 100-115.

7) Page, E. S. (1955). Control Charts with Warning Lines, Biometrika, 52, 243-257.

8) Page, E. S. (1957). On Problems in Which a Change in Parameter Occurs at an Unknown Point, Biometrika, 44, 248-252.

9) Shewhart, W. A. (1931). Economic Control of Quality of Manufactured Product. New York; D. Van Nostrand.

VARIATIONS FLOW ANALYSIS FOR PROCESS IMPROVEMENT

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SUMMARY

Variations Flow Analysis is a technique of evaluating the transfer of variations in stock, when the product from several machines at one processing stage is fed randomly to the several machines of the succeeding stage. This paper describes procedures, based on modifications of range methods for analysis of variance, which have been found of value in a large number of applications. The methods are illustrated with examples from yarn manufacture, but parallel applications in chemical processing and other industries are apparent.

INTRODUCTION

Variations Flow Analysis represents a special adaptation of analysis of variance technique, for tracing the transfer of variations in stock from process to process in multi-machine and multi-stage processing. By comparing actual variations against expected values in each department, it is possible to isolate and correct any places where excessive variations are induced into the processing sequence. Corrective action can then be concentrated on the places so isolated.

The analysis procedures have been simplified, so that the average supervisor in the industrial plant will understand them sufficiently to make his own applications. This feature of the procedures has been verified in actual practice and checked in industrial training courses over the past five years, in which attendants representing over a thousand industrial supervisors were given sample problems to work out.

The techniques described here are now used routinely in over a hundred plants, representing spinners and weavers of synthetic and natural fiber textiles. However, there are many other industrial processing organizations, particularly in the foundry and in the chemical plant, where these techniques of Variations Flow Analysis should be applicable in a similar manner. Thus, even though the discussion in the following may refer to within-machine and between-machine variation in a spinning process, parallel application in other industries, such as to variations within and between lots in Bessemer steel rolling become apparent. In describing the latter type of application, Weaver (14) deplores the difficulty of explaining variance analysis by means of conventional sums-of-squares techniques, a problem which the procedures in this paper seek to avoid by the use of methods involving ranges.

THE MODEL

The general model for which the Variations Flow Analysis techniques described here were developed is as follows: Production, from raw material to end product, involves several processing stages. In each stage, the product from one set of machines feeds at random into the several machines of the succeeding processing stage. At any stage, a blending may occur, whereby several units of the product are combined. A typical production process of this nature is manufacture of yarn in a spinning mill. The product from one set of machines feeds more or less at random into the machines of the next processing stage. Production is of the semi-continous processing type. Strands of product are extruded on a continuous basis on various spindles of one process; and when a package of several pounds has been produced, it is removed and then fed into the next machine. By means of successive attenuation of the stock, a rather bulky sheet of stock coming from the picker machines is gradually reduced to a fine thread of yarn in spinning.

At any processing stage, a special type of blending or "doubling" may occur, wherein several strands are combined into a single new strand. Usually, there is at least one such blending, which occurs in the drawing process. Here several strands are fed into the drafting rolls, where they are blended together. At the same time, attenuation by drafting takes place, which is usually large enough so that at any one output position of the frame, the individual strand of blended sliver produced has approximately the same weight per yard as each of the several slivers fed. It is apparent that the physical operations of blending and drafting are equivalent to the arithmetical process of adding and then averaging. Therefore, one of the results obtained is a reduction in variations of stock in accordance with the well known standard error of the mean effect. This statistical effect may have been recognized in intuitive form by Sir Richard Arkwright, when he developed the drawing frame (8).

In a typical mill, there may be from two to ten pickers, feeding more or less at random into from a hundred to three hundred cards. Each of these machines has one feed position and one output position. There may next be ten to thirty drawing frames, each with four input and output positions, followed by ten to thirty roving frames, and from fifty to three hundred spinning frames. A roving frame may have from eighty to 120 spindles, and a spinning frame may have from two hundred to four hundred spindles. The differences in number of units in each process is accounted by differences in production rates employed.

Depending upon the degree of diversification of a mill, there may be various lines of flow, with a particular raw material going over a particular set of machines to produce a particular yarn style. The Variations Flow Analysis must, of course, be carried out separately for each line of flow.

SUITABLE MEASURE OF VARIABILITY

In deciding upon a suitable measure of variability, consideration must first be given to the basic unit of measure. This unit, as obtained from tests known as sizing tests, is the stock weight or more specifically the linear density, usually expressed in such terms as "grains-per-yard" for sliver, and in the rather complex term "number of 840-yard lengths per pound" for roving and yarn. In listing the weight values for various yarns alongside the standard deviations, and repeating this for rovings and slivers, the author has observed that in general the standard deviation increases in direct proportion to increases in linear density. Thus, it appears that the coefficient of variation is a good measure of variability, since it permits ready comparison of different yarns, rovings or slivers, without need to refer to the particular weight involved. In the analysis shown here, the coefficient of variation, v, in per cent is used; however, it is apparent that the same analysis could be carried out in parallel manner in terms of standard deviations.

In tracing the flow of variations through successive processing stages, the following variation coefficients, in per cent, have been found to be of importance in each processing department:

1. Within-machine variation coefficient, v_w.

2. Between-machine variation coefficient, v_b.

3. Departmental-overall variation coefficient, v_o, which in view of the generally normal patterns of v_w and v_b is the Pythagorean total:

$$v_o = \sqrt{v_w^2 + v_b^2} \qquad (1)$$

When a machine has several output positions or deliveries, such as a drawing frame, v_m may again be broken up into within-delivery and between-delivery components. However, where this has been done by the author, it was usually found that the within-delivery component was of relatively minor magnitude. The analysis can therefore be simplified considerably by ignoring these smaller components.

Usual sizing test practice in a mill is to weigh 5-yard lengths of sliver, 12-yard lengths of roving and 120-yard lengths of yarn. Since the mill usually has a

large amount of such sizing test data available, taken for the primary purpose of controlling average stock weights in processing, it appears logical to use these same weighings also for analysis of variations. However, variance length curve analysis of textile strands, has shown that the observed variation along a strand varies, being largest for small lengths and decreasing asymptotically as the lengths increase (13). Fortunately, for the range of weights normally encountered in textile processing, the conventional test lengths used in a mill, fall within the asymptotic area of the variance length curve. Thus, the use of existing mill data in Variations Flow Analysis appears justified. The practical conventions were, of course, developed long before the statistical methods of variance length analysis, and related autocorrelation and correlogram techniques had arrived.

The case of sampling lengths, just as the prior case of blending, shows how the practical man can apply statistical principles correctly to mill problems, even though the theory of statistics as such has not as yet provided means to analyze such problems. There is, however, another field in which the practical man, and the practical mill production supervisor in particular, seems to have been less successful. This is in the field of realizing the effects of machine to machine differences. In particular, the supervisor may have been exceedingly good at setting up each of the machines in each department to produce good quality, with good uniformity. However, between machines, there may exist certain small but cumulatively important differences in roll diameters, gearings, settings and tensions, contributing to differences in weight between slivers, rovings and yarns. In the final assembly operation, weaving, these differences will then affect fabric appearance quality. Variations Flow Analysis will usually bring out these differences, as well as their likely causes, thus spurring corrective action.

FLOW OF VARIATIONS

From the general nature of textile processing as described, and the types of variation in weight found to be of importance, certain basic patterns governing the flow of variations from process to process become apparent. These patterns may be stated in the form of four Flow Rules, which have been numbered, so that distinct reference can be made to each in subsequent discussions in this paper. The Rules are:

Flow Rule 1: Since generally several machines at one process feed more or less at random into the machines of the subsequent process, the departmental overall variation of the first process is the input source of the within-machine variation of the next process.

Flow Rule 2: The within-machine variation of a particular process is the combined result of the input from the prior process and the effects of any additional variation that may have been introduced by the machines themselves.

Flow Rule 3: To the extent to which differences in average level between machines exist, they thereby contribute to departmental overall variation. The larger this between-machine variation, which is superimposed on within-machine variation, the greater will be the departmental-overall variation.

Flow Rule 4: Where channelling (or non-random flow) of stock occurs, the departmental overall variation may not show up immediately in the subsequent within-machine variation. Instead, it will then appear in the corresponding departmental overall variation of the process. For example, if there are differences in the average level between two groups of carding machines on the same stock, but each group channels into a distinct group of drawing frames, then this between-group difference on the cards will not show up in the within-machine variation in drawing; but it will show up as between-machine and therefore departmental overall variation in drawing. This fourth Flow Rule may be considered a special case of non-random flow, not covered by the first Flow Rule.

It is evident that from the configuration of variations data in a mill, one may predict the existence of channelling without ever having set foot in the plant. This, if fact, has been done successfully in numerous cases. It should be noted here that channelling, as described above, is always detrimental where the process into which the stock is channelled includes blending or doublings. In simple terms, if the somewhat heavy stock from one group of machines is not blended with the somewhat lighter

stock from the other group, then the "evening out" of differences cannot take place. In more technical terms, channelling of stock, by its selectivity or non-randomness, interfers with the (previously discussed) standard error of the mean effect in reducing variations.

Important improvements in variation, and greatly enhanced overall benefits, have accrued to mills that have recognized and eliminated channelling and its detrimental effects. This is especially important since differences in weight or linear density of stock may represent corresponding differences in such factors as degree of parallellization of the fibers, effectiveness of combing and carding action on the stock, and efficiency of removal of non-spinnable waste, such as short fibers, leaf and trash.

Allowing for Blending

It has already been demonstrated that the process of blending or doublings, accompanied by compensating draft, is equivalent to totaling and then averaging. Accordingly, by recourse to the standard error of the mean, and the assurance of the Central Limit Theorem (15) in case of (usually slight) deviations from normality, we may write the expectation formula:

$$v_{we} = v_{op}/n^{\frac{1}{2}} \qquad (2)$$

where v_{we} represents the within-machine variation expected at a given process, v_{op} represents the departmental overall variation of the prior process, and n equals the number of strands combined by blending in the given process.

This formula for the effect of blending of doublings has been found to work well in practice. However, a small allowance is usually added to the value of v_{we} to take account of the effects of drafting during blending.

Allowing for Drafting

Where drafting occurs without blending, the expected effect of draft might be expected, from analogy with (2) above, to be written:

$$v_{we} = (v_{op}) \times (draft)^{\frac{1}{2}} \qquad (3)$$

Where draft refers to the linear density of the stock fed divided by the linear density of the stock produced. Unfortunately, this formula does not work out well in practice. The reason is that, unlike the case of blendings where various strands of stock are combined at random, drafting without doubling is a non-random process along linear lengths of a single strand. The lengths exhibit generally a high degree of auto-correlation and non-normality. Thus, since there is absence of both random sampling and normality, the Central Limit Theorem becomes inapplicable. In place of Equation (3), it has been found necessary to set up special tests to evaluate the effects of draft, or to utilize empirical allowances (4,7).

CALCULATION METHOD

From the constant need to control stock weight in a mill, abundant test data are usually on hand for the analysis of the variations in stock. Table I shows an abbreviated* set of such data, representing randomly selected machines from each of which four random bobbins were tested. The following ranges were obtained:

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*Note: The 48 test results used in the illustration here represent a relative minimum of data. Usually, twice as many or more test results are readily available in the mill, and should be used, so as to minimize the loss in precision of the range method as against the sums of squares approach. The relative efficiency of the range in estimating the standard deviation has been the subject of prior investigations (5, 6, 9-11).

1. The range within each machine, R_w.

2. The range-overall, representing the range on any particular day across any row of test results, R_O.

3. The daily cross-range of the machine averages, R_a.

From Table II, the calculation of v_w is clear. The estimate of v_O is shown by Methods 1 and 2. While Method 1 is statistically the less efficient, it has the advantage of being more readily understood by foremen and other nonstatistical personnel. In particular, the calculation steps of Method 1 are parallel to the steps in determining v_w, and can thus be grasped intuitively; while on the other hand the additional steps of Method 2, shown in Line 10 seems to present considerable difficulty to intuitive explanation.

Any excessive between-machine variation could now be found from the squared ratio of the average of the cross ranges to the average within-machine range, as shown by David (2). However, for purposes of direct comparisons of coefficients of variation from process to process, as illustrated in Table VI, it has been found desirable to use a test involving the ratio of v_O to v_w directly. This is the modified F-ratio, which for the example at hand is found to be:

$$F_{mod} = v_O/v_w = 5.39/3.97 = 1.36$$

From Table IV, this ratio is found to be greater than the minimum F_{mod} ratio of 1.133 required for significance at the 5 per cent level, corresponding to $r = 4$, $k = 12$, thus showing that the overall variation is significantly greater than the within-machine variation. This indicates the presence of excessive between-machine differences, causing significant differences in average weight of stock coming from different frames. The causes, be they in roll weighting, tensions, or gearing, need correction so as to standardize the effective drafts among all frames.

More formal variance analysis procedure, using conventional sums of squares techniques, would have yielded slightly different estimates of variation coefficients and again a significant F-ratio for the excess of departmental overall over within-machine variation, as shown by the data in Table V.

A TYPICAL CASE HISTORY

The typical case history, in Table VI, may be used to illustrate how the method of Variations Flow Analysis works. For each processing stage shown, 20 samples were tested, with each sample consisting of four specimens per machine. Accordingly, it is found from Table IV that any $F \geq 1.097$ indicates a significant excess, at the 5 per cent level, of overall variation over within-machine variation.

For the first process, carding, the v_O of 5.2 is significantly higher than the v_w of 2.8, the F-ratio being greater than 1.097. Based on Flow Rule 3, this means that there are excessive differences in average level between the machines in the carding process. A subsequent investigation indicated that off-standard trumpet sizes and gearing were responsible for these differences.

The next process is drawing, in which a blending or doubling of sixteen strands of sliver takes place. Since generally several cards feed a particular drawing frame, the v_O of carding may be used to calculate the expected within-machine variation in drawing, based on Equation (2). Thus:

$$v_{we} = 5.2 \div \sqrt{16} = 1.3.$$

Table VI shows that the actual within-machine variation in drawing is only 0.7 in terms of per cent variation coefficient, which is considerably below the 1.3 theoretically expected from the formula. Accordingly, one must suspect that the normal pattern of flow, usually expected from Flow Rule, 1 may have been upset by channelling, resulting in the pattern observed under the special case when Flow Rule 4 applies. A subsequent check revealed these suspicions to be true. There were actually two makes of cards, Saco-Lowell and Platt, which were located in two sections, A and B, of the card room. The Saco-Lowell cards in section A had a slightly higher

Table I

Test Results on Spinning Bobbins. Data in Terms of Yarn Number*

Machine Number	43	27	5	16	Range, Overall	Range of Averages
Week 1	55.5	51.8	56.0	52.0	4.2	
	50.2	54.2	57.1	56.1	6.9	
	54.8	50.1	55.2	54.1	5.1	
	52.1	54.1	51.1	53.0	3.0	
Total	212.6	210.2	219.4	215.2		
Average	53.2	52.6	54.8	53.8		2.2
Range Within	5.3	4.1	6.0	4.1		
Machine Number	8	39	7	12		
Week 2	50.3	59.9	55.5	58.8	9.6	
	58.8	58.2	50.2	56.1	8.6	
	54.0	56.3	51.6	59.2	7.6	
	53.8	57.0	54.7	57.1	3.3	
Total	216.9	231.4	212.0	231.2		
Average	54.2	57.8	53.0	57.8		4.8
Range Within	8.5	3.6	5.3	3.1		
Machine Number	21	29	41	32		
Week 3	50.4	55.4	58.8	58.6	8.4	
	52.1	56.3	57.3	59.2	7.1	
	51.6	56.1	56.8	55.7	5.2	
	53.5	58.1	53.9	57.1	4.6	
Total	207.6	225.9	226.8	230.6		
Average	51.9	56.5	56.7	57.6		5.7
Range Within	3.1	2.7	4.9	3.5		

Grand Total: 2639.8   Grand Average: 55.0

*Yarn Number represents the number of 840 yard lengths of yarn per pound weight.

Table II: VARIATION COEFFICIENTS DETERMINED BY RANGE METHODS

	Computation Steps	Within-Machine	Departmental Overall		Between Machine-Averages
			Method 1	Method 2	
a.	Total of Ranges in Table I	54.2	73.6		12.7
b.	Number of Ranges Used, g	12	12		3
c.	Average Range, $\bar{R} = a/b$,	4.51	6.13		4.23
d.	Tests per Range, r or n,	$r = 4$	$n_o = 4$		$n_a = 4$
e.	Conversion Factor from Table III	0.483	0.483		0.472
f.	Standard Deviation, $\sigma = c \times e$	2.18	2.96		2.00
g.	σ^2 Estimated by $\hat{\sigma}^2$	σ_w^2	$\sigma_o^2 + \sigma_b^2$		$\sigma_a^2 + \sigma_w^2/r$
h.	Variation Coefficient, $\hat{v}$, $= 100 \, \sigma$ / Grand Average, (Grand Average $= 55.0$)	3.97	5.39	5.0*	3.63**
i.	Symbol for $\hat{v}$	$\hat{v}_w$	$\hat{v}_{o1}$	$\hat{v}_{o2}$	$\hat{v}_a$

* v_{o2} is found from $\sqrt{v_w^2 + v_a^2 - v_w^2/r} =$
$$= \sqrt{(3.97)^2 + (3.63)^2 - (3.97)^2/4} = 5.0$$

** v_a is used only as a stepping stone for finding v_{o2}.

<u>Subscripts</u>: w = within-machine, o = departmental overall, a = between machine averages, b = between machines, net. Carets, $\wedge$ indicate that the values shown are determined from sampling estimates.

TABLE III.   FACTORS FOR CONVERTING AVERAGE RANGE TO STANDARD DEVIATION *

Number of Ranges, g	Sample Size (Number of Tests per Range), r or n								
	2	3	4	5	6	8	10	12	15
2	0.781	0.552	0.465	0.417	0.385	0.344	0.319	0.303	0.285
3	.813	.565	.472	.420	.388	.346	.322	.304	.286
4	.826	.571	.474	.422	.389	.347	.323	.305	.287
5	.840	.575	.467	.424	.391	.348	.323	.305	.287
6	.847	.578	.478	.426	.391	.348	.324	.306	.287
7	.855	.578	.478	.426	.392	.350	.324	.306	.287
8	.855	.581	.481	.426	.392	.350	.324	.306	.287
9	.862	.581	.481	.427	.392	.350	.324	.306	.287
10	.862	.581	.481	.427	.392	.350	.324	.306	.287
12	.870	.585	.483	.427	.392	.351	.324	.306	.287
14	.870	.585	.483	.427	.394	.351	.325	.306	.287
15	.870	.585	.483	.427	.394	.351	.325	.307	.287
13	.870	.585	.483	.429	.394	.351	.325	.307	.287
20	.877	.588	.483	.429	.394	.351	.325	.307	.288
25	.877	.588	.483	.429	.395	.351	.325	.307	.288
30	.877	.588	.483	.429	.395	.351	.325	.307	.288
40	.887	.591	.486	.430	.395	.351	.325	.307	.288

Example: Given Average Range = 4.52, and 12 Ranges (g = 12) with each Range based on a sample size of 4 items or specimens (n = 4), then the Conversion Factor is 0.483, and the Standard Deviation is 4.52 x 0.483 = 2.18.

Source: Reciprocals of values of c, obtained from an extension of H. A. David's table in Biometrika 37, 271-280 (1950).

* If, in place of Average Range, $\bar{R}$, the Average Range Per Cent, $\%\bar{R}$, is used, then the Factors yield the Coefficient of Variation.

Table IV: VALUES FOR TESTING SIGNIFICANCE OF DIFFERENCE BETWEEN
VARIATION COEFFICIENTS, IN VARIATIONS
FLOW ANALYSIS (MODIFIED F-RATIOS,
$F_{mod.}$, 95% CONFIDENCE LEVEL)

Number of k	Sample Size (Number of Tests per Sample), r						
	2	3	4	5	6	8	10
10	1.453	1.223	1.150	1.113	1.091	1.066	1.052
12	1.393	1.197	1.133	1.101	1.081	1.059	1.046
14	1.351	1.178	1.121	1.092	1.074	1.053	1.042
15	1.334	1.170	1.115	1.088	1.071	1.051	1.040
18	1.293	1.151	1.103	1.078	1.063	1.046	1.036
20	1.272	1.141	1.097	1.074	1.060	1.043	1.034
25	1.234	1.123	1.084	1.064	1.052	1.038	1.030
30	1.208	1.110	1.076	1.058	1.047	1.034	1.027
40	1.173	1.093	1.064	1.049	1.040	1.029	1.023
50	1.145	1.081	1.056	1.043	1.035	1.026	1.020

Example: Given 12 samples ($k = 12$) each having a sample size of 4 specimens
($r = 4$), then $F_{mod.}$ is 1.113. If the actual ratio of the Variation Coefficients,
departmental-overall to within-machines exceeds this 1.113, then the departmental-
overall variation may be considered significantly greater than the within-machine
variation, indicating lack of standardization of effective drafts among the
machines.

Source: From formula $F_{mod.}^2 = 1 + (F-1)/r$, where F is given by Merrington and
Thompson, Biometrika 33, 80 (1946), with adjustments for use of ranges, based
on an extension of data tabulated by David, Biometrika 37, 271 (1950).

TABLE V: ANALYSIS OF VARIANCE CALCULATIONS FOR SIZING TEST RESULTS

		Sources of Variation		
Computation Steps	(1) Between Weeks	(2) Between Machines Within Weeks	(3) Experimental Error	(4) Total
a. Enter Squared Totals	857.4^2 $+891.5^2$ $+890.9^2$	212.6^2 $+210.2^2$ $+219.4^2$ etc. for all 12 totals		55.5^2 $+51.8^2$ $+56.0^2$ etc. for all 48 totals
b. Sum of "a"	2,323,610	281,562		145,548
c. Tests/each "a"	16	4		1
d. b ÷ c	145,226	145,390		145,548
e. Sum of Squares	$d_1 - C^*$ $= 48$	$d_2 - d_1$ $= 164$	$e_4 - e_{1,2}$ $= 158$	$d_4 - C$ $= 370$
f. Degrees Freedom	$3-1=2$	$3\,(4-1)=9$	36	$48-1=47$
g. Mean Square, e ÷ f	24.0	18.2	4.4	
h. F-ratio	$g_1 \div g_2$ $= 1.32$	$g_2 \div g_3$ $= 4.14$		
i. Significance, %	Nil	99.5		
j. Component of Variance	$\dfrac{g_1 - g_2}{c_1}$ $= 0.36$	$\dfrac{g_2 - g_3}{c_2}$ $= 3.45$	g_3 4.4	$g_{1,2,3}$ 8.21
k. Std. Dev., $\sqrt{j}$	0.60	1.86	2.10	2.87
l. Variation Coeff.	1.09	3.38	3.82	5.09

* C = Correction Factor = $(\text{Grand Total})^2 /$ Total Tests = $(2,639.8)^2 /$ 48 = 145,178

TABLE VI: VARIATIONS IN STOCK WEIGHT FOUND IN A TYPICAL MILL

| | Variation Coefficient, Per Cent | | |
Processing Stage or Department	Within-Machines $(\hat{v}_m)$	Departmental Overall $(\hat{v}_o)$	Modified F-Ratio $(\hat{v}_o/\hat{v}_m)$
Carding	2.8	5.2	1.857*
Drawing	0.7	1.8	2.571*
Roving	2.0	2.8	1.400*
Spinning	3.2	3.4	1.063

* Significant at 5 per cent or better, since F_{mod}, for $r = 4$, $k = 20$ is 1.097.
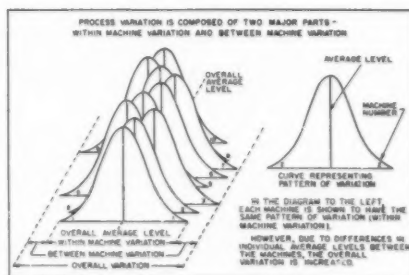
Figure 1 — How within-machine plus between-machine variation combine to produce overall variation. (Reproduction from Enrick, N. L., "Quality Control," courtesy Industrial Press, New York.)

draft, thus delivering somewhat lighter stock than the Platt cards in section B. Correspondingly, the Platt cards with a somewhat lower draft, were delivering heavier stock. This difference in stock weight had contributed to the high departmental overall variation on the cards, which was noted above. Now, when pushing the cans of sliver from the cards to drawing, the tender would naturally push them the shortest distance. And, while there was a certain amount of randomization of the cans, in general the relatively light stock from the Saco-Lowell cards would go to the group of drawing frames closest to section A, while the somewhat heavier stock from the Platt cards would go to the group of drawing frames closest to section B. Within each drawing frame, the variations input was thus either from Saco-Lowell cards or from Platt cards. Following Flow Rule 2, each drawing frame would thus reflect the group-overall variation fed from either section A or section B of the cards, which was less than the departmental overall variation, for the simple reason that the group-overall for each section did not include the effect of difference in average level between the two groups. Thus the full amount of departmental overall variation was not fed to any one drawing frame, resulting in an actual within-machine variation which was less than would have been expected under fully random flow of stock to each drawing frame.

One might suspect from this example that channelling is actually beneficial, since the variation observed within the machines was less than expected under random flow. Actually, however, only a temporary advantage is observed. The differences between the two card groups continue to be reflected in the form of differences in weight of the stock, and will now show up in a high overall variation in drawing. Examination of Table VI shows that the actual overall variation is indeed high, with a coefficient of 1.8 per cent. The channelled flow has prevented the lighter stock from the Saco-Lowell cards to meet the heavier stock from the Platt cards in the blending operation of the drawing frames. This has minimized the effectiveness of blending (in particular, the effectiveness of the standard error of the mean law to operate) and has resulted in a higher overall variation than would have been obtained under fully random flow of stock. In particular, without channelling it might have been expected that the within-machine variation in drawing would have been only slightly above the 1.3 per cent predicted from Flow Rule 1 and Equation (2). The overall variation, in the absence of differences between drawing frames, would have been at a corresponding level. The actual overall variation, at 1.8 per cent, must thus be considered unduly high as a result of the channelled flow. It is interesting to note that the mill subsequently shifted the carding machines, alternating the two makes among adjoining floor positions, so that in the future there would be relatively automatic randomization of the flow from the two types of cards the drawing frames. This insured better blending in drawing and, combined with a correction of off-standard trumpets and gearing on several of the cards, resulted in substantial improvements in card and drawing sliver uniformity of weight.

Continuing the analysis, it will be noted that in roving the within-machine variation exhibits a coefficient of 2.0 per cent, which is generally in accordance with expectation, based on Flow Rule 2, and a small allowance for the effect of drafting in roving. The overall variation of 2.8 per cent is significantly in excess of the within-machine coefficient. Applying Flow Rule 3, a check of equipment was made, which revealed differences in gearing, roll diameters and cone belt starting positions among the roving frames, to be responsible for this excess variation.

In the final yarn making process, spinning, the within-machine variation with a coefficient of 3.2 per cent is consistent with the variations input from roving, departmental overall, under Flow Rule 2. The overall variation in spinning is not significantly higher than the within-machine variation, indicating that there are no harmful between-machine differences between the spinning frames.

The Variations Flow Analysis thus demonstrated places in carding, drawing and roving where excessive variations were being induced into the processing. Moreover, from an examination of the Flow Rules, the nature of this excessive variation is known. In this particular case history, the subsequent corrective actions taken, as outlined above, resulted in an eventual reduction in the overall variation coefficient of the yarn from a relatively medium 3.4 per cent to a relatively good 2.6 per cent. This is only one example, however. The validity of Variations Flow Analysis has now been confirmed in experience in over a hundred plants. The importance of the technique is enhanced by the fact that, accompanying reductions in

variation of linear density or stock weight, there are improved processing conditions, in the form of lowered strand breakage rates in spinning the yarn and in subsequent weaving, storage yarn, and improved appearance quality of the more uniform product obtained.

DERIVATION OF MODIFIED F-TABLES

The Modified F ratio values have been computed from Merrington and Thompson's tables of the distribution of Snedecor's F, using the expression:

$$F_{mod}(k,r) = \sqrt{1 + (F - 1)/r}$$ (4)

Where F is an abbreviation for $F(k,r)$. In calculating F_{mod} the use of ranges was considered, by making an appropriate reduction of approximately ten per cent in the Degrees of Freedom, based on Duncan's tabulated data (2). Further details of derivation were previously published (3,4).

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A PRACTICAL ANALYSIS OF A SUCCESSFUL SQC INSTALLATION IN HIGH QUALITY, HIGH STYLE GARMENT MANUFACTURING

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At the risk of sounding like an inquiring reporter, I am going to ask those of you who do not already have an SQC program several questions. Are you willing to sever connections with the traditional, and embark on a new, profitable and proven method of controlling your quality? Are you satisfied with the quality level of your product, or do you wish to steal a march on competition and become a leader in your field? Are you capable of approaching seemingly radical ideas with an open mind, and are you capable of recognizing and admitting past managerial weaknesses or deficiencies?

If in answering these questions it becomes apparent to you that there is room and desire for improvement in your organization, then perhaps this paper can be of benefit to you. For it tells, in some detail, of the successful installation of an SQC program at the Hathaway Shirt Company's largest plant, located in Waterville, Maine. Perhaps some of the ideas and methods I shall tell you about will be advantageous and adaptable to your situations. I sincerely hope so, for in this day of sometime shoddy American production it behooves all of us to leave no stone unturned in searching for tools and methods which will provide us with a maximum level of desirable quality. For those of you already having SQC installations, I hope this text will be interesting and that it will promote an interchange of ideas which would be beneficial to all of us.

Hathaway has been a name synonymous with quality for over a hundred years. We proudly consider ourselves the style and quality leader of the shirt manufacturers in this country. It would be safe to say that quality is Hathaway's life blood, and, should it become diluted or tainted, Hathaway would undoubtedly fail. Our intention for the future, as it has been in the past, is to expend all possible effort and thought to achieve a maximum quality level unequaled in the American market.

It was with this intent in mind that Hathaway's management asked Kurt Salmon Associates, Inc. of Washington, our consulting engineers, about the feasability of installing an SQC program. Mr. Robert E. Heiland, who incidentally is Chairman of the Textile and Needle Trades Division of the ASQC, explained the potential benefits to be derived from such a program and shortly thereafter, in the fall of 1958, the first steps were taken toward the installation of SQC.

Hathaway had the traditional type of 100% inspection found in most garment plants today. This inspection system, however, was probably unique in the industry in that there were no fewer than eleven 100% inspection points located in the dress shirt stitching area. This same type of intensive quality inspection was also being applied to sport shirt and Lady Hathaway production. Although the protection received from this type of costly and detailed inspection procedure provided a garment of superior quality, we did not feel fully satisfied that we were utilizing our efforts to the best and most efficient advantage. The following points seemed to be increasingly apparent.

1. 100% inspection is monotonous with the inspectors becoming robotlike in their reactions. Such mechanical inspection is not sensitive to subtle but undesirable changes in quality.

2. Traditional inspection systems are designed to sort good work from bad but are incapable of preventing the occurrence of bad work by catching it at the needle as it occurs. To illustrate this fact let us consider an operator on collar closing, who might be producing bad quality due to machine troubles or emotional disturbances. Her defective work would remain undetected until all subsequent operations on the collar were performed and the defects reached inspection. Often a period of several days elapsed before detection occurred. By that time, many dozen bundles had been produced in a defective manner by the collar closer. What we wanted was a method of catching bad work as it occurred at the needle, and thus prevent defective work from accumulating.

3. Another weakness of 100% inspection was that unit supervision was responsible for its functioning. Inspection, therefore, became far more susceptible

to production pressures than common sense said it should be. Furthermore, supervision was not equipped with the proper facilities, personnel, or time to maintain a continuous check of each operator's quality level.

4. Various quality experiments were conducted at Hathaway over the years prior to 1958, in efforts to assure better quality. At various times a staff member would become "Quality Director" and take over the supervision of 100% inspection. All these experiments failed, sometimes because line supervision thereupon attempted to abdicate its responsibility, and also from a lack of statistical knowledge, and the resulting inability of staff and production people to evaluate fairly most quality problems.

In proposing a new quality installation for Hathaway, we were assured that the above mentioned weaknesses of 100% inspection systems would not occur with the plan of SQC known as "Skip Bundle Sampling". The following seven claims were made for the program.(1)

1. That it would be capable of application without adding to the total manufacturing cost.

2. That it would be simple enough to be administered by existing plant personnel.

3. That it would be sufficiently discriminating to apply pressure immediately to those operations where quality had deteriorated below a tolerable level.

4. That it would be sufficiently powerful to force real improvements at trouble spots when the trouble occurred.

5. That it would provide accurate statistical data to enable management to really control quality and would provide a reliable, objective grading system for each operator in the plant.

6. That it would be flexible in order to permit shifting of control emphasis as the need appeared.

7. That it would recognize the basic fact that sewing room quality is controlled almost entirely by people, not machines.

After a careful survey study of our quality problems, costs, and desired quality levels, the use of Skip Bundle Sampling appeared to be feasible and economical to our management. I was assigned to spearhead and to supervise the installation under the technical guidance of Kurt Salmon Associates, Inc.

It was decided to begin our installation in the Dress Shirt Stitching room, rather than in Cutting or Finishing. This was done for several reasons. It seemed that the greatest quality improvement potential lay in the stitching room. Furthermore, by maintaining the status quo in the finishing room, we obtained an objective barometer of quality changes taking place in stitching.

At this point I shall briefly describe the Skip Sampling plan we have adapted for our stitching operations. Bear in mind this plan applies only to Stitching, not Cutting or Finishing in which other sampling plans are used. Furthermore, one of the attractive features of Skip Bundle Sampling is that it is a flexible quality tool and, therefore, while the plan I shall describe applies to most stitching operations, we have changed it on certain occasions to better fit specific needs. In general terms, here is the way our plan works.

We knew, as I am sure you do, that some operations contribute much more heavily to the overall defect level than do others. In our Dress Shirt Stitching, where some seventy to eighty operations are performed on each shirt, there were ten or twelve operations accounting for over 80% of the in-process defects. Thus, in each unit, and by unit is meant a group of related operations which manufacture a particular part of the garment, there were one or two critical quality operations. It was at these operations we first directed our attention. In most instances I did the initial week or two of sampling or inspection. Then qualified personnel were trained and assigned to these key operations as "samplers".

Samples are drawn, on a random basis, from bundles representing one-fourth of each critical operator's daily production. It is important to note that this is a random

selection and does not involve every fourth bundle. Bundles used for sampling purposes
are drawn from the most recently completed production. This gives an evaluation of work
as it leaves the operator's needle. From each bundle selected, twenty items are
screened. These items are also selected on a random basis from within the bundle. The
effect of such random selection is, of course, to insure that the operator will not be
able to predetermine what portion of her work or which items will be screened. If upon
inspection these items satisfy our established quality requirements, the bundle is re-
leased to the next operation. If a defect (or defects) are found in the bundle, it is
returned to the operator responsible.

It is at this point that the true effectiveness of Sampling becomes apparent. Under
our 100% inspection system defective work was removed from a bundle, tied in a separate
stack by the inspector, and returned to the operator by unit supervision. The operator
then repaired her mistakes and returned them to the inspector who replaced them in the
correct location in the original bundle. With Skip Sampling the procedure is markedly
different. After a random sampling of twenty pieces has been completed and the exact
results recorded on appropriate forms, a bundle with one or more defects (that is, a
rejected bundle) is returned to the operator by the sampler. Defective pieces are not
pulled out of the bundle, however, and the responsible operator is required to reinspect,
on her own time, the entire bundle, repairing all defective pieces she may have sewn.
She then returns the repaired bundle to the sampler who resamples it following the orig-
inal sampling procedure of choosing twenty random pieces. If acceptable the second time
the bundle is released. If not acceptable it is returned, after notation has been made
on the operator's record card, and the operator must rescreen the entire bundle again.
Work returned a second time is returned through unit supervision. Obviously, rein-
spection of entire bundles on the part of a piece worker is costly and distasteful to
her. If an operator is not quality conscious at the inception of sampling she quickly
becomes that way as her earnings reflect her carelessness.

I should like now to digress for a moment and make the following observation,
stated first by Mr. Heiland, and later corroborated by our experience. Defective work
is seldom produced on a consistent basis. If an operation produces 4% bad work it is
more than likely producing 2% defective work 90% of the time and 22% defective work 10%
of the time. In short, defective production seems to be of a cyclical nature.

With this fact in mind, let us return to our explanation of Hathaway's Skip Bundle
Sampling. When an operator produces defective work it puts us on warning that perhaps
a defective cycle is beginning. To counter this condition the skip interval of one
bundle in four being selected ceases and every bundle produced by the operator under
suspicion is sampled until two consecutive bundles are found to be acceptable. One
effect of this feature is to ensure that the cause of defective work is corrected,
whether it be machine trouble, operator carelessness, or a training or methods problem.
When the quality level deteriorates badly, the amount of sampling required increases
until it becomes impossible for the sampler to cope with it. At this point, management
must do something to return conditions to normal.

Thus, in Skip Bundle Sampling a variable proportion of production is examined, not
a fixed proportion. The extent of variability depends on the amount of defective work
being produced; the higher the percent defective, the larger the proportion of produc-
tion which must be inspected.

Since this sampling method appeared sensitive to immediate fluctuations of quality,
as they occurred at the needle, and since it seemed to provide sufficient penalty to
discourage sloppy work habits, it was hoped that shortly after sampling installations
were made, 100% inspection operations could be eliminated. Such proved to be the case
as we progressed through the "parts" units.

Using conventional notations for the sample size, n; the average bundle size, N;
the acceptable number, c; the skip interval, S; and the clearance interval, m; our plan
may be expressed as follows.

$$N = 21 \qquad c = 0 \qquad m = 2$$
$$n = 20 \qquad S = 4$$

At this point, it should be noted that the highest average outgoing quality level,
or AOQ, occurs when a process is running slightly under 6% defective. At this point the
AOQ level is 2.73% defective. The AOQ decreases as the process runs higher than 6% due
to the increased amount of inspection required. This relationship is shown by Figure 1.
This AOQ factor compares most favorably to our old 100% inspection protection. I under-
stand that recent studies made by various garment engineering firms indicate that 100%

TABLES OF VALUES OF AVERAGE OUTGOING QUALITY AND AVERAGE
FRACTION INSPECTED FOR THE SAMPLING PLANS:

	N 21		N 42
	n 20		n 20
	c 0	AND	c 0
	S 4		S 4
	m 2		m 2

$\bar{p}$	AOQ	AFI N 21	AFI N 42		$\bar{p}$	AOQ	AFI N 21	AFI N 42
.000	.0000	.238	.119		.052	.0272	.711	.591
.002	.0019	.259	.136		.054	.0272	.722	.605
.004	.0038	.280	.153		.056	.0273	.734	.618
.006	.0057	.300	.170		.058	.0273	.745	.632
.008	.0076	.321	.187		.060	.0273	.757	.645
.010	.0094	.342	.204		.062	.0271	.766	.659
.012	.0109	.363	.223		.064	.0269	.776	.673
.014	.0124	.384	.242		.066	.0268	.785	.686
.016	.0139	.406	.262		.068	.0266	.795	.700
.018	.0154	.427	.281		.070	.0264	.804	.714
.020	.0169	.448	.300		.072	.0261	.812	.724
.022	.0180	.467	.320		.074	.0258	.820	.735
.024	.0191	.486	.340		.076	.0254	.827	.745
.026	.0202	.506	.359		.078	.0251	.835	.756
.028	.0213	.525	.379		.080	.0248	.843	.766
.030	.0224	.544	.399		.082	.0244	.849	.775
.032	.0231	.561	.418		.084	.0240	.856	.784
.034	.0237	.578	.437		.086	.0236	.862	793
.036	.0244	.594	.455		.088	.0232	.869	.802
.038	.0250	.611	.474		.090	.0228	.875	.811
.040	.0257	.628	.493		.092	.0223	.880	.818
.042	.0260	.642	.510		.093	.0218	.885	.825
.044	.0263	.656	.527		.096	.0214	.890	.833
.046	.0266	.671	.544		.098	.0210	.895	.840
.048	.0269	.685	.561		.100	.0205	.900	.847
.050	.0272	.699	.578					

KSA/RH
3/59

FIGURE 1

inspections actually average only slightly higher than 50% effective.

Before actual steps were taken to install Sampling, management, floor supervision, and engineering got together to establish definite, realistic, and mutually acceptable quality standards. Opinions existing at that time were far from unanimous and the resulting "meeting of the minds" in itself helped to improve our quality situation.

In further anticipation of our SQC installations, detailed records were kept at our 100% inspection stations. These records were to give us an invaluable means of comparison between the effectiveness of traditional inspection vs. Sampling. We shall consider several of these records shortly.

I shall not attempt to describe in detail the actual installation of Skip Sampling in each individual unit. It will suffice here to make the following observations which apply to the overall progress of the Stitching room program.

Although there was 100% skepticism on the part of supervision, management, and operators when this program was originally suggested, it has now become fully accepted and supported by practically all concerned. This welcome fact has been accomplished in several ways.

At no time was the installation pushed ahead without proper preparations having been made. These consisted of a thorough evaluation of existing conditions and objectives and a detailed and candid explanation of Skip Sampling methods to all persons concerned. The program was "sold" to the operators largely on the basis that Sampling would improve the quality of work coming to them and thus make their jobs easier. Furthermore, the operators were assured that a detailed record of individual earnings would be maintained and, if it appeared that Sampling was unfairly reducing their earnings, temporary bonuses would be applied to piece rates. This was done in several instances.

It is significant to note here that <u>average unit earnings have increased noticeably</u> since the installation of Sampling, even after the temporary bonuses had been removed. This has been brought about not only by the improvement in quality, but also by the fact that sampling was quick to pinpoint areas of mechanical, supervisory and training weaknesses. It is an accepted fact now at Hathaway that the ability of Sampling to focus attention on weaknesses found in all phases of production has been nearly as beneficial and desirable as its ability to control and improve an individual operator's quality output.

Although individual operators whose quality was considerably below our acceptable level were severely affected by Skip Sampling, our program has been installed with virtually no Union opposition. This is, in my opinion, strong testimony to the value of advancing slowly and patiently, with an open mind and sympathetic approach to individual problems as they arise.

One of the most important elements involved in the construction of a quality program is the selection of capable people to become inspectors, or samplers as we call them. We have tried to select people who have the capacity to grow with their job and who have the ability to win the confidence of the unit people they sample. With only one or two exceptions our 100% inspectors were incapable of becoming samplers. In several cases we took a top producer from an operation and made her a sampler. This apparent robbing of production paid for itself in a relatively short time, as the sampler's ability not only to detect bad work but to demonstrate corrective and efficient methods quickly helped raise unit production levels. Regardless of previous experience, we have stressed that our samplers must be fully familiar with all quality specifications, that they must approach their stitchers with humility and a sincere desire to assist, that they must be unbiased, and that they must be capable of making routine decisions on their own without becoming dependent on floor supervision for advice or comfort. We have been fortunate in our selection of samplers, as is attested by the low turnover of samplers, the measurable improvement in quality, and the lack of Union opposition.

A most valuable tool provided management by an SQC program is found in the form of statistically accurate and reliable records. We have tried to keep our recordings confined to the most essential details. Should a need for more detailed knowledge of specific aspects of quality production be desirable, additional information can be amassed with a minimum of effort and cost by using existing data-collection methods. Indeed this has been done several times in the past. Our current utilization of records is as follows. Once a week production management has a quality meeting, chaired by our

production vice-president. Prior to this meeting a weekly grading sheet is published which lists all Stitching, Cutting and Finishing units sampled, their production, number of samples taken, and their percent defective quality. Units are graded as "good" if their defect level is less than 1%, "fair" if they average 1% to 2½%, and "poor" for an average of over 2½%. Another sheet is run off every week which lists all operators averaging over 4% defective per week. These reports are discussed in detail at the weekly meeting and corrective measures are taken when necessary. Operators who appear on the defect list for the first time are verbally warned by supervision. Repeat appearances within a three month period result in written warnings and possible dismissal.

We can see by now that Skip Bundle Sampling directs management's attention to those operations, people, machines, and materials which are responsible for poor quality. It does this in several dramatic and convincing ways. One is by providing sound statistical evaluations of unit and individual quality levels. Another, as previously explained, occurs when an operator or operation runs consistently worse than an acceptable level. When the volume of required inspection is too much for the sampler to manage, supervision has to take some action to straighten the problem out and get work flowing again.

So far I have briefly described the Skip Bundle Sampling plan used in our stitching rooms. We have also installed Sampling in our cutting and finishing rooms so that now we cover all production operations in both Dress and Sport shirt lines at our Waterville plant. We are currently installing Sampling in our staple stock plant at Lowell, Massachusetts.

In our installations in Cutting and Finishing, different types of sampling plans were used. These differ mainly in the size and type of sample taken. The penalties invoked for poor quality are much the same in all cases, with the operator being required to reinspect his entire production unit in which a defect occurs. For the sake of time and space I shall not go into the details of the various sampling plans used but, should anyone be interested, I would be happy to discuss them at another time.

Now to consider the all-important question of "How well has Sampling worked for Hathaway?" I can definitely say it has worked very well. To offer specific evidence of quality improvement, I have included in this paper Figures 2 and 3. Figure 2 illustrates the percent defective work being found at different parts units before and after Sampling. It also reflects the reduction in personnel needed to perform the quality inspection. I believe this is a rather impressive comparison of the past and the present. Figure 3 indicates the percent of defective work reaching our final inspectors from all stitching operations before and after Sampling. Again these figures speak for themselves. Similar improvement has been statistically verified in Cutting and Finishing. The seven specific claims made earlier in this paper for Skip Bundle Sampling have been corroborated by our experience. We are confident that our quality has improved and will continue to do so. I do not wish to lead you into thinking that Hathaway has solved all her quality problems. Such is not the case. Currently we are struggling to apply foolproof controls to our fabric flaw problem. But we feel that Sampling has given us the tools to work with and, with perseverance and ingenuity we should soon be even farther ahead of our quality position of five years ago.

In closing I should like to bring forth these observations.

1. As should be expected, this type of program creates more problems than it solves during the initial stages of installation, but it solves many more than it creates after becoming established. This is a fact which is all too easy to lose sight of during the period of "growing pains".

2. Skip Bundle Sampling is not a program to be embarked on lightly. It is not capable of being established effectively if it is applied in haste or without competent engineering advice. We found that generous initial expenditures of time and money, where they appeared necessary, were most profitable. Hathaway, as is the case with most garment manufacturers, had no statistically trained staff capable of initiating such a program. Without the knowledge provided by outside professional engineers, this program would never have risen off the ground.

3. Finally, as is the case with all aspects of production, this type program is ultimately dependent on the desire of management and supervision to make it work. Without cooperation from all production departments, such an installation will bog down and fail. My function in this program has been largely one of sales and diplomacy. It is imperative that someone unite such tradi-

QUALITY LEVEL COMPARISON OF DEFECTS FOUND AT DRESS SHIRT PARTS
MANUFACTURING--PRESENT VS. SURVEY PERIOD

	SURVEY PERIOD 11/24-12/12/58		POST SAMPLING PERIOD 1/14-2/11/61			
	% DEFECTIVE	NUMBER OF INSPECTORS	% DEFECTIVE	NUMBER OF SAMP. PTS.	NUMBER OF SAMPLERS	% CHANGE
CUFFS	2.10	3	1.44	1	1	-31.4
FRONTS	7.19	4	3.56*	2	2	-50.4
COLLARS	14.66	4	7.49*	3	2½	-48.9
BACKS	4.69	2	1.93	1	½	-58.9
TOTAL	28.64	13	14.42	7	6	-49.65

* THIS PERCENT IS TOTAL OF NUMBER OF SAMPLING POINTS

FIGURE 2

COMPARISON OF REPAIRS FOUND AT FINAL TRIM AND INSPECT BEFORE
AND AFTER ELIMINATION OF 100% INSPECTION IN MANUFACTURING UNITS.

	OPERATION	1. #/24-12/12/58 % DEFECTIVE	2. 10/5-10/12/59 % DEFECTIVE	3. 12/5-12/10/60 % DEFECTIVE	4. 2/20-2/25/61 % DEFECTIVE	*
1.	CUFFS	0.24	0.45	0.59	0.13	
2.	SLEEVES	0.03	0.08	0.02	0.08	
3.	BACKS	0.12	0.14	0.01	0.15	
4.	FRONTS	0.32	0.30	0.36	0.47	
5.	COLLARS	0.78	0.10	0.25	0.31	
	TOTAL-PARTS UNITS	1.49	1.07	1.23	1.14	-23.5%
1.	JOINING					
2.	COLLAR SET AND FINISH	3.10	0.83	2.09	2.20	
3.	BUTTON AND BUTTON HOLE BAND					
4.	SLEEVING AND FELLING	4.79	0.47	0.89	1.27	
5.	CUFF SET AND FINISH					
6.	BARTACK	6.33	1.29	1.91	1.00	
	TOTAL-ASSEMBLY UNITS	14.22	2.52	4.89	4.47	-68.6%
	ALL MANUFACTURING	15.71	3.59	6.12	5.61	-64.3%
	FLAWS, HOLES, ETC.	1.96	2.08	1.79	2.13	+ 7.9%
	GRAND TOTAL	17.67	5.67	7.91	7.74	-56.2%

*INDICATES % CHANGE BETWEEN COLUMNS #1 AND #4.

FIGURE 3

tionally independent and uncooperative departments as Cutting, Stitching and Finishing. Once these groups start pulling together and become "sold" on the capabilities of SQC there are few problems that can not be solved quickly and easily.

If you have an earnest and eager desire to improve your quality position, and are capable of channeling your management's efforts toward this goal, you will find, as Hathaway has, that Skip Bundle Sampling will be a most effective tool.

(1.) "Skip Bundle Sampling—A New and Economical Method for Process Control in the Sewing Room." Robert E. Heiland, Research Director. Kurt Salmon Associates, Inc.; Textile Quality Control Papers, Vol. 6, 1959, published by The Textile and Needle Trades Division, ASQC.

MOISTURE CONTROL IN THE CASHMERE INDUSTRY

by Stanley Breen, General Manager
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INTRODUCTION

During the past four years a new system of measuring and controlling the moisture content of fibrous materials - protein - cellulose, and synthetic has been in use by a number of manufacturers in many different branches of the textile industry. This paper will review how this system is applied in the processing of Cashmere.

Cashmere is the fiber from a goat native to certain areas of the Middle and Far East. In the treatment of this fiber it is necessary to maintain moisture control during wet and dry processing operations and finally bring out the finished product at a standard moisture content.

Moisture content of Cashmere, in common with all textile fibers, is significant in two main areas of operation: processing control and accounting: It is well known that weighing, conveying, carding, spinning, knitting, dyeing, weaving, and finishing operations are only controllable if the amount of fiber is known and the moisture adjusted for optimum quality and efficiency. The accounting operation is concerned with the value of the textile fiber from the standpoint of price. In buying and selling, value is dependent on moisture content because almost all textile fibers are hygroscopic. Fibers vary in normal moisture content from 0.5% to 13%, and in price from 10¢ to $20. per pound. Cashmere is currently priced in the range from $5. to $12. per pound. Contracts are written for payment based on clean dry fiber present to a specific regain, or shipped weight with a moisture content not to exceed a specified amount. In either case it is necessary to measure and report moisture to the most accurate value possible.

The system described determines the moisture content to the most accurate standards now possible, which permits delivery of the best possible product at a cost within controlled and predetermined schedules.

THE MEASURING SYSTEM

The fundamental approach of the moisture control system described herein is the following: An instrument capable of measuring large samples quickly is used on the production floor. This instrument is calibrated by laboratory methods and monitored by these same laboratory methods. We thus substitute rapid secondary measurements for slow primary (laboratory) methods and use the laboratory method on a reduced scale to "Quality Control" the secondary method. The secondary system was designed to measure a large sample to achieve better representation of a lot. The combination of the large sample and rapid measurement insures representation of the lot and "present time" information which permits accurate control during processing.

Moisture content measurements during production were made on instruments which measure the dielectric constant of the fiber. Examples of instruments are shown in Figures 1, 2, 3, and 4. Figs. 1 and 2 show a Forte' Electronic Moisture Content Analyzer, Model K. Figs. 3 and 4 show the Model D. The Model K determines the moisture content of a 1¼ pound sample of bulk or staple fiber. The Model D measures the moisture content of an entire ball of wool top, which weighs between 16 and 22 pounds.

A measurement is made by inserting the sample in a test cell, closing a lid, and reading a meter which is scaled in arbitrary units of 0 to 100, proportional to dielectric constant. An electric field passes through the entire sample producing a dielectric effect essentially equal to the

ASQC LCS Code 720:70:423

average dielectric constant of the mass within the field enclosure. By
choosing proper field constants, the change in dielectric constant
measured depends mainly on water rather than extraneous impurities or con-
ductivity. To calibrate the instrument, samples are drawn from production,
weighed to 20 ounces for the Model K or weighed as "catch weight" on the
Model D, and "read" on the panel meter. Parts of these samples are then
sent to the laboratory to be oven dried by conventional means. A plot is
made of meter reading vs. laboratory moisture and smooth curves drawn for
lines of constant weight. Sub-samples are drawn for laboratory tests,
rather than drying entire samples, for economy of time and practibility.

PRACTICAL USE IN CASHMERE PROCESSING

An actual case will be used to explain and illustrate the system.
In the processing of Cashmere the terminal moisture can be adjusted by
controls available to the machine operator. Thus, it is only necessary
that he have access to instantaneous, accurate, and representative informa-
tion regarding the moisture content of the product. Machine operators draw
1½ pound samples and control the moisture content by sampling, adjusting,
resampling, and readjusting. Experienced operators have little difficulty
reaching control and there is little or no oscillation or hunting. In
addition, they must record hourly, the moisture content of a sample as
produced. A typical hourly control diagram from production at Forte'-
Fairbairn, Inc. is shown in Fig. 5. The measurements were made on a
Model K by shift machine operators.

Calibration of the instrument was effected by drawing five sub-samples
of 10 grams each from the 20 ounce sample. These were dried to constant
weight at 105°C and the loss of weight reported as moisture. The average
of the five was used as a data point and plotted against "meter reading".
Monitoring of the instrument is accomplished by a similar process except
samples, in triplicate, are drawn only once per twenty-four hour working
day. The moisture content by Forte' Model K is tabulated against moisture
content by laboratory; differences are taken, and a control diagram plotted.
A control diagram covering a typical 8 day period is shown in Fig. 6. This
control diagram contains the differences due to sampling and oven drying
only 50 grams from the 570 gram total sample.

A further check is made independently by the Quality Control Depart-
ment by means of opening bags of Cashmere on the loading dock, drawing
samples, and measuring them for moisture by laboratory methods. The
sample selection is purely random. These tests are expensive to make be-
cause drawing the samples requires cutting open bags of stock; hence they
are made infrequently. This final control measures what the customer
receives. A plot showing a typical four month period is shown on Fig. 7.
The moisture content at this point is dependent on storage conditions as
well as the initial moisture condition of the stock.

SUMMARY

Our experience indicates a machine operator can measure and control
the moisture content of in process Cashmere to a specification value with
a standard deviation of $\sigma = 0.25\%$ moisture content. The instrument corre-
lation to laboratory, including the limited sub-sampling, is approximately
the same order of magnitude. Long term studies of shipments indicate
stock is delivered at slightly lower than specification moisture content.
Without modern instruments and systems of this type, it was not possible
to control moisture content of processed Cashmere.

FIGURE 1

FIGURE 2
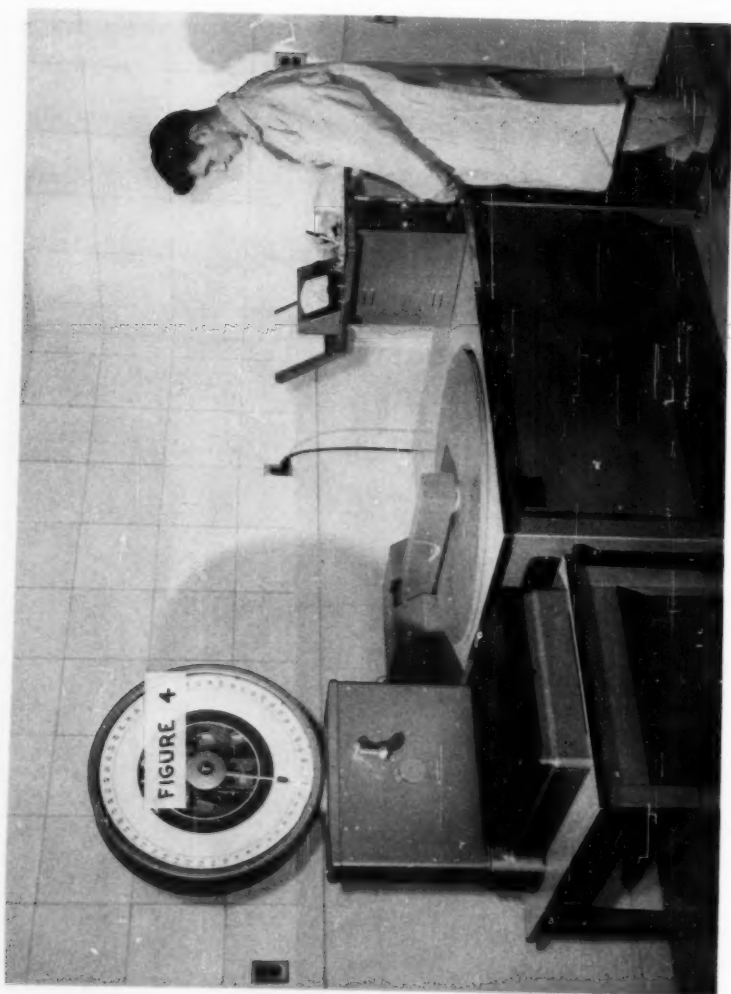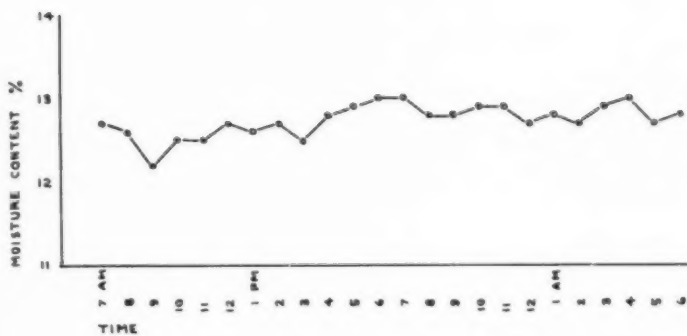
FIGURE 3
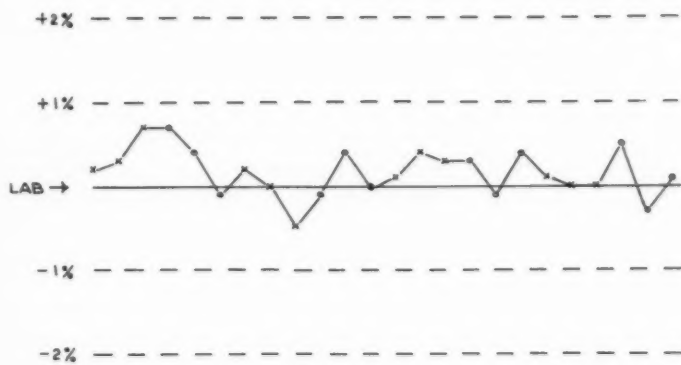
FIGURE 4
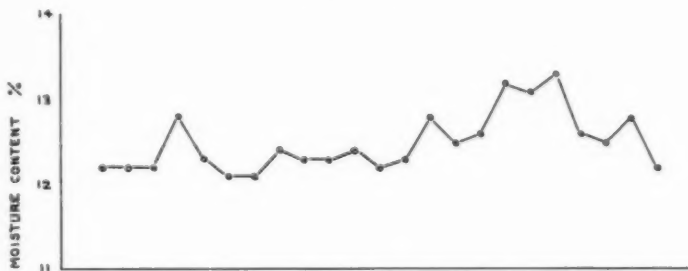
FIGURE 5

FIGURE 6

FIGURE 7
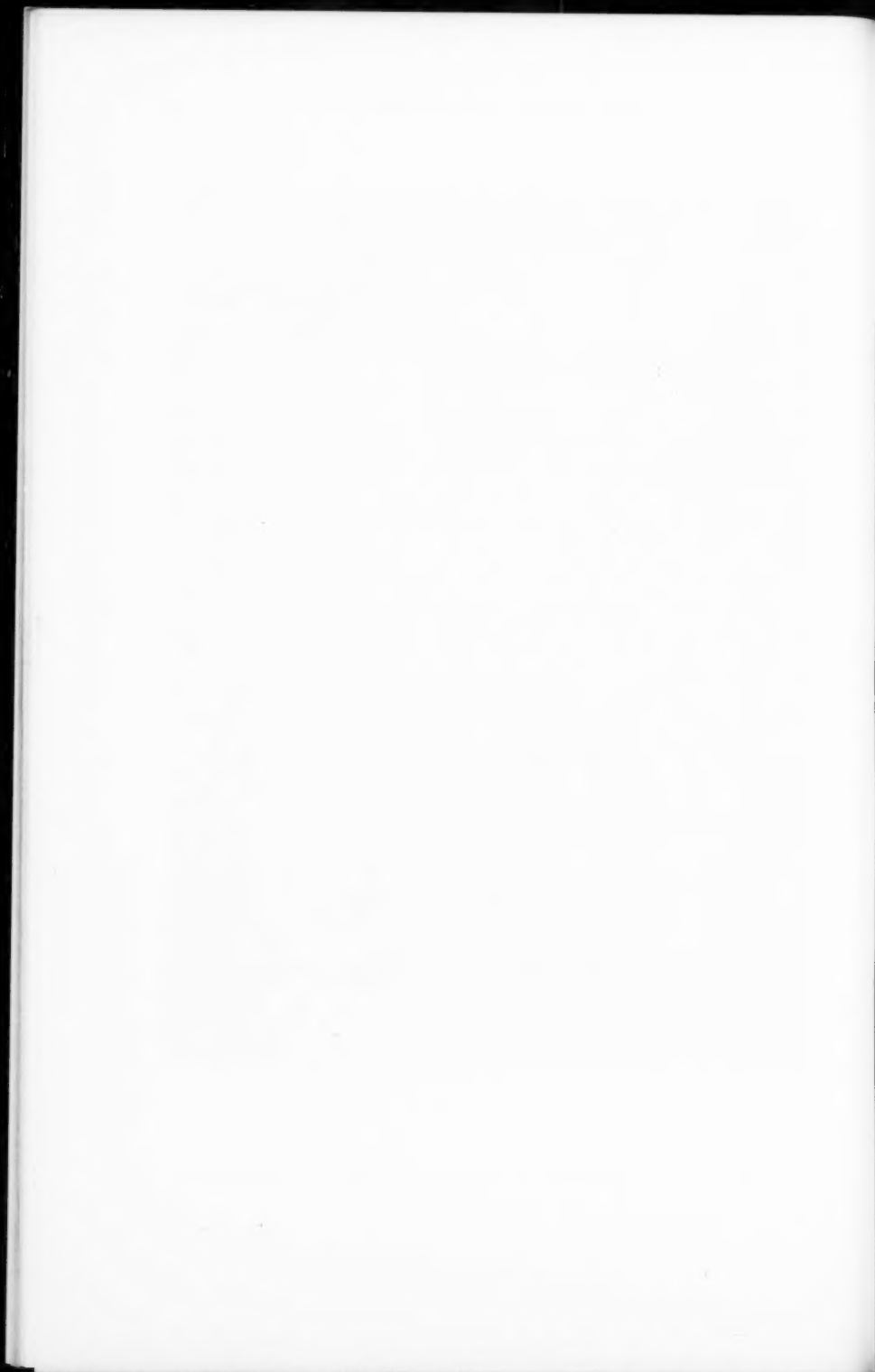
SQC TRAINING FOR THE CHEMICAL INDUSTRY

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Abstract

This paper discusses what chemists and chemical engineers need to know about statistical quality control and other statistical methods, where they should seek these ideas, what types of training should be of interest to them, kinds of problem orientation they are apt to have, the pros and cons of undergraduate and postgraduate training, the possibilities of on-the-job training, what's being done by interested societies and what's missing. With such tremendous scope it should be evident that these are simply notes to stimulate discussion.

WHY TRAIN?

College interviewers are asking potential employees, "Have you studied statistical quality control or statistics?" Properly used, the payoff from these methods is substantial in time, new knowledge, superior process control and reduced losses. "Why train?" is better restated in terms of "who, how soon, how much, where, and what topics?" In spite of the best theoretical approaches, much profitable chemical processing is still based on empirical understanding and in some cases is nothing less than a highly prized art. Effective process control speeds identification of key process variables, and interrelations. Recent work has gone far to link empirical studies, their results and interpretations with theoretically postulated mechanisms. Statistical methods play a large part in this attack by engineers, armed with computers, experiment designs, process simulation and systems analysis on intricate multi-million dollar plants. Much of this is beyond the scope of this discussion but serves well for reference.

It is as serious to overtrain as undertrain. Training is expensive, takes the time of the most knowledgeable people and generally disrupts routine operations. Therefore, any plan for an individual or a company must be tailored to its specific needs, abilities, attitudes, tempo and degree of sophistication. The returns are greatest for those having the least statistical knowledge. This is generally true until the most advanced methods are used when another higher dollar return level can be sought.

To avoid giving the impression that chemical industry statistical requirements are unique, it is useful to describe them in more detail.

WHAT DO CHEMISTS AND CHEMICAL ENGINEERS NEED TO KNOW ABOUT SQC?

The statistical quality control needs of chemists and chemical engineers are not substantially different from those of quality control people in other industries. Primarily, they need to have a keen awareness of variation. In addition to this and its ramifications, it is important that they associate the differences between their industry and others with different ways they should use statistical quality control techniques. For example, they will want to associate systematic and random errors with those parts of laboratory equipment and laboratory methods from which they are likely to occur.[7] They should be keenly interested in the concepts of accuracy and precision as well as recognizing that laboratory testing is as much of a process and worthy of control as their manufacturing processes.[6] Thus a need for statistical control of a laboratory chemical test method will be as important as statistical control for in-process assurance. Their interest in sampling will extend even further than that of piece parts to the general problems of bulk sampling.[5] The general principles are the same but the application and interpretation differ. Since chemists and chemical engineers are generally indoctrinated in the "how to do it" aspects of laboratory methods, it is extremely instructive to select a relatively simple method and perform routine tests on a standardized solution to get a feeling for the kinds of variation that tests contain. These technical people have been heartily criticized for thinking only in terms of a single measurement primarily because they do not recognize the need for suitable replication of the test.

WHERE SHOULD THEY GET THESE IDEAS?

Ideally, these notions should be planted in college and nurtured in industry. As suggested, a little bit of on-the-job experience helps considerably in understanding variability. This means that laboratories, usually a starting place for greenhorn chemists or engineers, provide opportunities for simple application of control charts and statistical methods. Too often we neglect college laboratories where calibration of laboratory equipment and the examination of repetitive test results can give additional training. The basic idea of quantitative analysis and the repetition of tests or experiments in Physics Laboratories should provide additional strengthening of the concept of variability.

Unfortunately, from a training standpoint, the standard deviation of most chemical and physical test methods is relatively small. This suggests that destructive tests of some kind should be considered for greater emphasis on the importance of controlling test method precision. Practical demonstrations of the strength of materials is suitable.

In mathematics courses other than statistics, a study of calculus offers an opportunity to review the effect of errors or discrepancies on estimation. In engineering course work, studies of instrumentation and systems design should permit some discussion of the effect of noise or random signals and the difficulties associated with delay in automatic sampling and testing devices.

To effectively consider training in the chemical industry it is important to appreciate the problem orientation chemists and engineers have on the job. These can be divided into three groups: Research and Development, Laboratory Control, and Process Control. The basic knowledge for all of these is substantially the same, with the exception that the first two have greater emphasis on more precise experimentation and measurement methods. On the other hand, if any substantial investment is involved, a new process or a modification of an old one will eventually go either into a pilot plant, semi-works plant, or have one or more full scale plant runs of its own for verification purposes. This means that production engineers need to know a good bit about statistical quality control and statistical methods for planning experiments with full scale equipment. Since the field is very large the interested reader is referred to reference [1] for additional information from a problem orientation viewpoint.

PROS AND CONS OF UNDERGRADUATE AND POSTGRADUATE TRAINING

Ideally, every chemist or chemical engineering graduate should have at least one statistics course under his belt. Unfortunately, the concepts of statistics and SQC are only one among many that belong among his guiding principles on graduation. This competition and the only recent appreciation of the value of statistical methods in the chemical industry has allowed the competition to get there first with the result that statistics is not included in the curriculum.

Fortunately, SQC and the concepts of experimental designs can be gained in postgraduate courses offered in many universities. Two things are needed on the part of the student; one is awareness of the need to know SQC, and the second is sufficient sensitivity to appreciate the application of the methods in his own industrial environment.

Unfortunately, postgraduate courses vary widely in content, availability and evenness (reflecting the competence and experience of the instructor). Furthermore, chemical industry employees are frequently transferred from one geographical region to another making a consistent plan difficult to complete. The best solution to date for the ambitious engineer seems to be that of the 6 week summer session offered jointly by North Carolina State College, Virginia Polytechnic Institute, University of Florida and Oklahoma State University. Under this program a M.S. in statistics can be obtained in about 3 summers. A contribution must be made by both the student and his company to make the 6 weeks stay each year possible.

ON THE JOB TRAINING

Because of these factors, there is a substantial effort in medium and large size companies to provide training of chemists and chemical engineers on the scene. Although this is a function of the size of the companies and of their overall capability in statistics, it is possible through the use of consultants to conduct on-the-job short (5-10 day) courses. Most of the companies that have undertaken such programs have done so because they are progressive toward new methods and because they have had

successful applications of the techniques in one or more plants. In many cases, the
training has been undertaken for a limited number of students selected because of their
ability to sense problem requirements and to identify types of solutions.[4]

To make the most of this kind of training, the chemical companies must provide in-
ternal consultation for interested students who learn statistics and proceed to try it
out. Nothing is more deadly than to try statistical methods on a job, assume that you
have used them correctly, write a glowing report and then discover a basic misunder-
standing of an assumption has scuttled all your dollar savings.

In many instances the complexity of the chemical problems makes the solution with
statistical techniques extremely time consuming unless a computer is available. How-
ever, computers are becoming more and more common in chemical companies. (This adds a
new dimension to quality control training - how to use computers.[2] Not only does
this enhance the solution of these more difficult problems but it also makes it possi-
ble to provide routine solutions for control chart data and things of this nature.
(Chemical companies are well known for the small size of their technical staff. This
means that routine data analysis has to pass quite an ordeal of fire before it gets on
any computer.)

Finally, a very important item for any training is strong management understanding
and support of the activity as well as tolerance of the time that must be set aside for
continued consultation and follow through.

SHORT COURSES

In addition to the on-the-job training courses which run the gamut from basic con-
trol charts through tests of significance, linear regressions and design of experiments,
a number of short courses are being offered jointly sponsored by universities and tech-
nical societies. The Chemical Division of the American Society for Quality Control has
been prominent in devising and offering new courses of this type. Stemming from an
original 10 day basic Quality Control course for the Chemical Industry instituted at
Rochester Institute of Technology, whose content for the most part is identical to
other basic QC courses but whose overtones and applications are very specifically aimed
at chemists and chemical engineers, extension has been offered to design of experiment
10 day courses. In addition to this, based on the publications of Box and Wilson, and
Box, Hunter, Hader and others, 3 day courses in response surface methodology have been
offered and successfully carried out in the U. S. These 3 day sessions provide the in-
terested chemist or engineer with basic notions of how to solve regression problems
using the abbreviated Doolittle Method, analysis of variance for linear models, the
principles of replication, ideas on first order and second order designs, augmenting
first order designs to make second order designs, concepts of lack of fit and mathe-
matical fitting of response surfaces.

For the chemist or engineer who has done considerable work with statistics, the
Chemical Division of ASQC has developed a 10 day course designed to present and discuss
the latest techniques of statistics that should have good strong application in the
chemical industry. The first of these was offered at The Harvard Business School in
1958 and the second was held at The University of Western Ontario in 1959. These 10
day sessions are not for beginners but have been well received by those attending.

Recognizing these special requirements of control chemists has led to the design
of a 3 day course in analytical techniques specifically for chemists. A course enti-
tled "Evaluation and Interpretation of Physical and Chemical Testing Methods" was
successfully conducted at Philadelphia in 1960 by the Chemical Division ASQC and ASTM
for this purpose.

Two day courses in Evolutionary Operations[3], a concept of G. E. P. Box designed
primarily to obtain information for improving processes from the normal running of the
process itself, using 2 and 3 factor factorial designs in plant operation, have been
carried out over various parts of the nation with good acceptance. These techniques
have been selected for teaching due to their special pertinence in this industry. Re-
ports of successful applications have helped.

The Gordon Research Conference of the AAAS held each summer provides a different
kind of training. The sessions on statistics in chemical engineering basically offer
discussion of papers presented either by statisticians or by chemists or engineers.
With only sufficient number of engineers to keep the balance on the chemical side, the
meetings aim to provide full review of what's new as well as what's needed.

One very important approach to training for the chemical industry which should not be overlooked is that of home study. As yet, no correspondence courses are available at the level and for the type orientation that chemists and engineers generally have. However, a number of professors have been good enough to provide guidance for engineers sufficiently motivated and yet remotely located so that it has not been possible for them to study at a university. Obviously, the return is directly proportional to the amount of effort the student applies.

WHAT'S MISSING?

The primary problem with each of these training methods is that of simulating control information and applying it in such a way and with sufficient repetition so that confidence is quickly obtained. Statistical methods must be used to be learned and appreciated. A second problem in the chemical industry relates to the relatively infrequent demands placed upon chemists and engineers for strong mathematical backgrounds. Although the concepts of partial differential equations may be discussed in undergraduate programs, the level of sophistication of chemical engineers in general is not mathematically as great as that of electrical engineers. With the advent of systems approaches to automation more emphasis on mathematics should provide greater readiness for statistics and SQC training. One of the major gaps that exists in the application of SQC in the chemical industry lies with failure to recognize instrumentation requirements as well as the random nature of measurement error. We have only begun to bridge the gap of optimizing process control. This requires understanding of such techniques as dynamic and linear programming, lagrangian multipliers, operational calculus, etc.

ROLE OF THE SUPERVISOR IN TRAINING

Another interfering element in the application of statistics in the chemical industry has been the failure of chemical management to recognize that statistics and chemical engineering are each full time jobs. While there have been exceptional chemical engineers who have been capable of learning and applying statistical methods to a sufficient degree to make the most of them, they are relatively few in number. Those that have been successful statistically usually gravitate toward statistical consultation in chemical companies. The net effect is the loss of a good chemical engineer; however, with effective team operation this loss can be quickly rectified.

The student must not be led to believe that techniques and chemistry are enough for industrial problem solving. His supervisor will offer much more support if he sees evidence of proper balance between methods and problem identification, diagnosis and practicality of solution including an adequate inclusion of the pertinent human relations aspects. However, the supervisor must encourage the student to use his new skills at every appropriate opportunity. Obviously, the student must not play the role of a hunter with a new gun in pursuit of any game it can kill, but instead, must pick and choose among his methods for the correct one for each particular problem. Students must try out their new skills soon after learning them for increased confidence and retention. Those given adequate encouragement by their supervisors have inevitably done better than those feeling that it was just another method. Another difficulty in providing training of this type relates to how much experience a chemist or engineer must have before he can fully appreciate the value of statistics. In some cases, a life time is not enough. For others, spacing the lectures or discussion periods over a year can be sufficient to provide opportunity for stimulation and student application. In other chemical situations greater success is had with continuous training programs, such as 5 day courses. Obviously, it is very difficult to free key people for 5 successive days from any operating division. This has led to the obvious compromise of one or more days a week over the equivalent number of weeks with homework assignments and on-the-job data collection and analysis as requisite.

CLOSING COMMENTS

In considering how to set up and conduct a training program there are several principles to keep in mind to insure success. These are more pertinent to organizations unaccustomed to formal training programs than to others.

1. Start small, put the ideas to work and aim to show savings in time, effort, and preferably dollars.
2. Try out new ideas before including them in the syllabus.
3. Get and use competent statistical consultation for planning, reference, and ideas on effective presentation.
4. Expand as soon as the students seem ready.
5. Train continually by plan rather than sporadically. Better to space out

a sound plan than rush an over-ambitious one.

6. Use training aids for maximum effectiveness. These include notes, charts, models, simulators, and props as well as change of pace, different types of presentation (lecture, discussion, demonstration, etc.).

7. Avoid getting everyone into the act. Select both the students and the course content. Tailor-make with examples from your business.

8. Maintain a strong feedback to assure the students and teacher are together.

9. Select the training staff carefully. Not everyone can or should teach, but few admit it. Use the experts for consultation and preparation of handouts, concise examples, etc.

10. Keep the discussion as close to actual plant or business situations as possible without getting embroiled in non-pertinent arguments. Introduce several new statistical ideas each session and review them each time for better understanding. Keep a "What Did He Say?" score-card in front of the class to list new statistical terms.

11. Encourage, support and recognize the students as they learn and use their new learnings. Get others to do likewise.

SQC has much to offer all chemists and chemical engineers -- not just those doing quality control work. Since it is results that count, training must be given to make the use of the methods simple and automatic. While zeal on the part of the instructor will add fire to his lectures, an enthusiastic student is our immediate goal.

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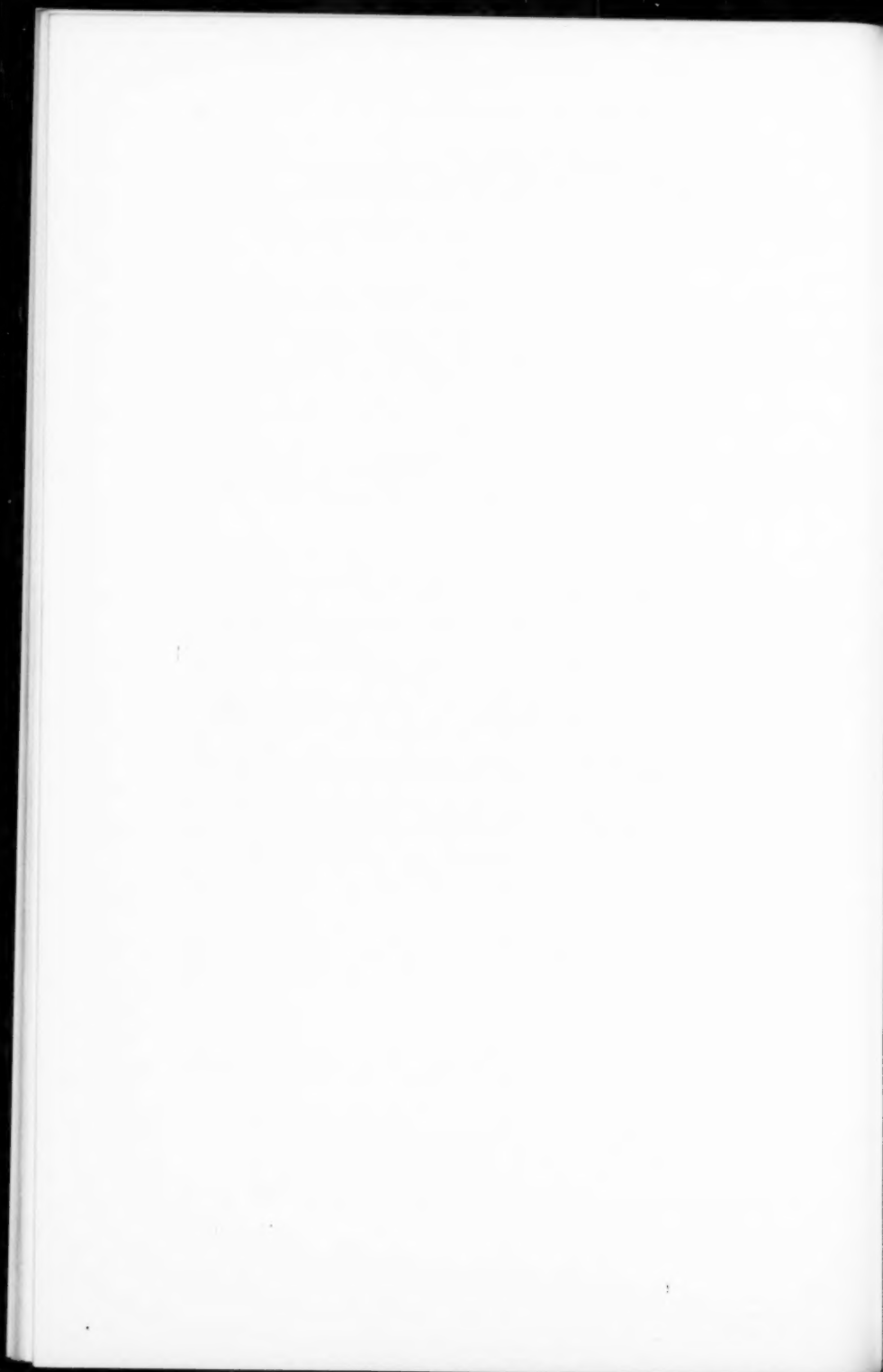
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INTRODUCTION

There are two fairly widespread but nevertheless erroneous notions about control charts that have impeded their application in some areas. These are:

(1) That "our product is different" and so control charts are not applicable.

(2) That our process must be more-or-less in control and the product rather homogeneous before we can use control charts to advantage.

Actually, if we can make satisfactory measurements on our product, its nature has no bearing on the applicability of control charts; and control charts can be very useful in getting a process into control, as well as keeping it there. The material in this talk illustrates both these points.

STATEMENT OF THE PROBLEM

We have a continent-wide telephone network, the purpose of which is to allow any one subscriber to converse with any other, with ease and dispatch. To this end, connections must be made correctly and rapidly, and the volume and quality of the speech transmission must be satisfactory. The volume of speech transmitted on a switched call is the characteristic that we are concerned with here. It depends principally upon the attenuation of the various trunk circuits employed. This can be readily measured in decibels.

The toll network consists of thousands of individual facilities or trunks, working between designated points; for example we have something like 100 trunks operating between New York and Montreal, 370 between Montreal and Toronto, 315 between Toronto and Hamilton Ont., etc. These individual facilities may be of radically different design. some are carried on open-wire, some on cable, some on microwave radio channels. Carrier systems, using the frequency spectrum above the voice range, are used extensively. Altogether we may have something like twenty or thirty different kinds of systems, but any individual circuit may be carried on one type of system, or may be built up of different systems in tandem. The lengths of the trunks differ radically as well, from a few miles to thousands. There is at least one thing that all these trunks have in common, regardless of how they are made up or operate en-route, they all appear as simply a pair of wires at the terminating points.

The switching of calls through this extensive network follows a definite pattern, known as the General Toll Switching Plan. A schematic of this is shown in Figure 1.

With Direct Distance Dialing (DDD) which will be universal on the continent about 1965, our crossbar toll switching equipment works automatically to channel calls according to this plan.

Toll offices are classified as:-

	example:	
1. Tributary	example:	Paris, Ont.
2. Toll Center		Brantford
3. Primary Center		Hamilton
4. Sectional Center		Toronto
5. Regional Center		Montreal

We have two regional centers in Canada, Montreal and Regina, and perhaps a dozen in the U.S.A., such as White Plains, N.Y., Pittsburgh, Chicago, St. Louis, Dallas etc.

LCS Classification   720 : 70 : 548
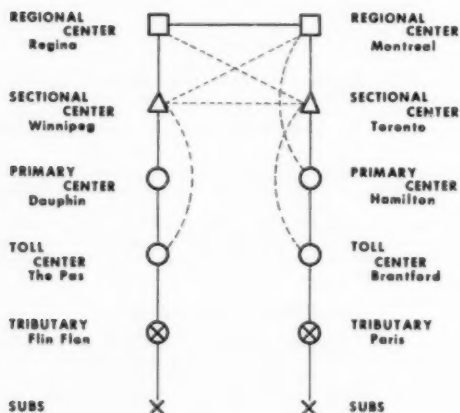
Fig. 1 - General Toll Switching Plan

In general, calls from tributaries to distant tributaries are routed up this line to the regional center, which has direct connection to all other regional centers. It routes the call to the regional center of the distant tributary, and then down the line to the distant tributary. This process is frequently short-circuited to a degree, where some of these links are by-passed by "high-usage" groups of facilities. However, under conditions where high-usage groups are found busy, the call is routed via the backbone routing of the toll switching plan. We may get as many as nine trunks connected in tandem on a toll call.

It is vital to the successful operation of this scheme that the transmission losses actually experienced in the individual trunks do not deviate excessively from their designed losses. If we design a trunk for 2 db loss, and we find when we measure its loss it is anywhere $\pm$ 5 db from this value, we will be in serious trouble when a number of such trunks are switched together for a call.

What we are interested in here is trunk net loss deviation, the difference between measured loss and design loss, or:-

Trunk net loss deviation = (Measured loss) - (Design loss) in decibels.

These values, for all our facilities, form a distribution, and this distribution, in general, can be considered as approximating the familiar normal shape.

When this matter was first investigated some years ago (perhaps I should say some decades ago) it was thought that the spread of this distribution $(\pm 3\sigma)$ might be about $\pm$ 2 db. It was actually found, in many offices, to be nearer $\pm$ 6 db. This represents a standard deviation of 2 db. If we have a toll connection through our maximum 9 trunks in tandem, it is like selecting nine individual trunks at random from this distribution, and adding them up. The standard deviation of the distribution of connections with 9 trunks would be $\sqrt{9} \times 2 = 6$ db, and the total spread of this distribution $(\pm 3\sigma)$ would

be $\pm$ 18 db. 5% of our 9 link calls would be more than $\pm$ 12 db. from what they should be, resulting in excessive loss and can't hear conditions at one extreme of the distribution, and howling or extreme echo conditions at the other. This is simply intolerable for the successful operation of our switching plan.

Obviously, improved maintenance was called for. Progress has been made to this end over the years, to reduce the amounts of these deviations, and, in general, to reduce the spread of the distribution of deviations.
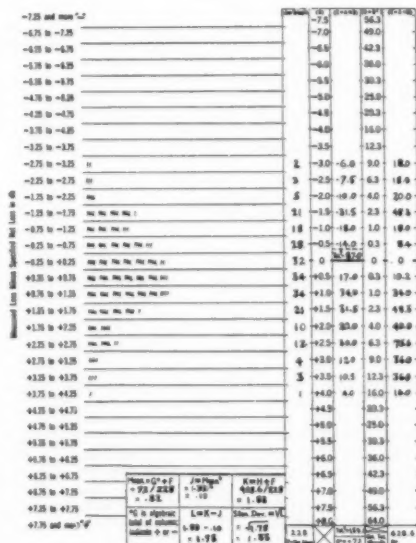
Fig. 2 - Stroke Chart

This has been done by maintaining stroke-chart histograms of trunk loss deviations in toll test rooms, calculating the mean and standard deviation of these distributions, and taking corrective action (at least in theory) against all cases where the deviation was found to exceed $\pm$ 2 db. An objective, or bogey, has been set up - a standard deviation of not more than 1 db and mean of not more than 0.25 db.

In this procedure, using a stroke chart histogram to judge when action should be taken to correct a trunk net loss deviation, progress was made up to a point, but in

many offices, after years of effort, it seemed impossible to better a standard deviation of 1.35 or thereabouts. Some reasons for this were:-

(a) So many facilities required attention on this basis that proper investigation to determine assignable causes was frequently not undertaken, and a compensating adjustment on terminating equipment was often resorted to. This latter just constituted another assignable cause which would be evident if the original trouble cleared.

(b) There was no clear distinction between assignable and chance causes, and no real knowledge forthcoming as to just what value of standard deviation was within the design capabilities of the system.

THE APPLICATION OF CONTROL CHARTS

In this situation, the use of Control Charts seemed like a good bet. A decision was taken to run a trial in one office for a period of one year. In order to judge effectiveness, it was undertaken that the standard deviation of distribution of loss deviations of these trunks should be brought below the bogey of 1 db. by the control chart method. This was in the face of over a year's operation by stroke charts prior to this, in which 1.35 db. seemed to be about the attainable minimum.

Bear in mind that in this application, we are dealing with something having inherently more variability than what we are accustomed to expect in a manufactured product; we have many different kinds of systems, in many different lengths, and sometimes combinations of systems in some individual trunks. By-and-large, though, we can classify our toll circuits in roughly four broad groups:-

1. Voice frequency cable and open wire
2. Open wire carrier
3. N and K carrier
4. Microwave.

On each c these first three classifications we ran a separate control chart. In the trial office we did not happen to have any microwave facilities terminating.

All of the trunks controlled by the trial office were less than 200 miles in length. Separate charts and standards would have been maintained on long facilities if any had come under the trial.

The control charts used were not strictly the conventional X-bar and R charts, in that σ' for the X-bar chart was computed from the overall distribution of deviations, rather than from the average range, and, therefore, it included a component of between-group variability as well as the within-group variability. The reason for this is that we admittedly are not dealing with things quite so "identical" as manufactured products. Even if we were dealing only with a specific type of facility, there are differences in length, which could involve quite a few "chance" causes. Hence we allow something for between-group variability. This may be reduced as assignable causes are found and removed, and eventually we may be able to compute σ' from R-bar.

Let us outline the procedure in detail. A routine had been established whereby, each quarter, a large sample of the trunks coming under the control of the office was examined for net loss deviation, and from this, $\bar{X}$ and σ' calculated, using the stroke chart. It was desired to interfere with this routine as little as possible. The procedure used was as follows:-

1. Three separate X-bar and R charts were maintained, in the following general classifications:-

(a) Voice frequency cable and open wire
(b) Open wire carrier
(c) N and K carrier

2. The quarterly sample was divided into rational sub-groups of 4 each, that is, each group of 4 would comprise trunks as alike as possible in make-up and length, with the same terminal points.

3. Measurements were made in each direction of transmission, on each sub-group of 4, and the results recorded on a form. Each form therefore covered the equiva-

lent of 2 rational sub-groups of 4 each.   X-bar and R were calculated for these groups.

Fig. 3 - Form for Recording Data

4. All observations for the quarter in each general classification were recorded on a stroke chart, and σ' computed.

5. $\bar{X}$ and R charts were plotted, currently with the observations, using the following limits:-

for the $\bar{X}$ chart: Central line $\bar{X}$ $= 0$

$$UCL = + \frac{3\sigma'}{\sqrt{n}}$$

$$LCL = - \frac{3\sigma'}{\sqrt{n}}$$

for the R chart: Central line $= \bar{R}$ for the base period

$$UCL = D_4\bar{R}$$

$$LCL = 0$$

6. All out-of-control points were investigated to find and remove the cause of the trouble, with as little delay as possible. All trouble found and removed was recorded. All sub-groups showing plots within control limits were left untouched.

7. At the end of each quarter, revised control limits were calculated for the following quarter. These were calculated from the variability experienced in the quarter ending, with the following conditions observed:-

   (a) The out-of-control points in the quarter were ignored in the calculation of the new limits, because they had been corrected.

   (b) If nevertheless, by chance, the new limits were wider than the previous limits, the limits were not relaxed and the previous limits were retained for the subsequent quarter.

RESULTS

By this procedure, it was possible to bring the standard deviation of the distribution of trunk net loss deviations down from about 1.35 db. to 0.93 db. within the trial period. This was within the bogey of 1.0 db. and hence a matter of some satisfaction. But to me, probably the most satisfaction came about the third quarter of the trial, when reviewing the results with the foreman responsible for carrying out the trial. I asked him to estimate the amount of effort being expended on the trial compared to the amount expended previously when it seemed impossible to improve on $\sigma = 1.35$. After some thought, he said:- "Even including the time it took us to learn about the control chart method, I think we are spending only about 80% of the time we spent previously". This is the meaning of the quotation "Better Quality at Lower Cost".

The essence of the process is that action is taken only when it is highly probable that assignable causes are present and can be found. This directs effort into con-

structive channels, and reduces effort expended in pursuing minor causes, difficult to
find, and which do not contribute much to total variability. Only after major con-
tributing causes are found and removed, is there much to be gained from going after
minor things. But the Control Chart, by itself, only points out where action can be
taken with profit. It is the action taken that improves things. If we don't act to
discover and remove causes, we won't get improvement.

What are some of the things the charts brought out? Let us look at some very
abbreviated versions of some of the charts.
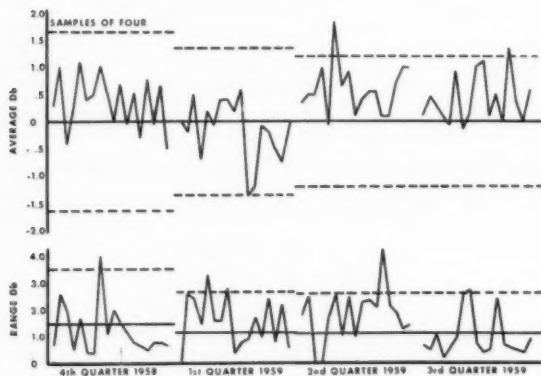
Fig. 4A - Abbreviated Control Chart - Cable & Open Wire Voice Frequency
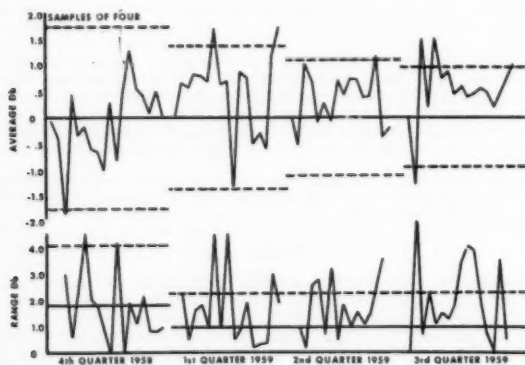
Fig. 4B - Abbreviated Control Chart - N & K Carrier

Whenever an out-of-control point was recorded, an investigation of the facilities in the sub-group involved was immediately undertaken. Frequently it was a range outage, with only one circuit in the sample of 4 at fault. This could be traced to a specific maladjustment, faulty tube, or similar cause. Occasionally an average would be out, which would indicate a cause common to all four in the sample, such as the gain adjustment of a carrier repeater, common to all four trunks.

It was even possible to detect some quite general causes from the pattern of the chart above, even although no out-of-control point was involved. For example, a regular saw-tooth pattern in the X-bar chart on voice frequency facilities between the same two points, indicated that there was an error in the level of the one-millivatt tone supply used in the measurements at one of these locations. In general, the rule is not to take action when a control limit is not exceeded, but this pattern indication was so obvious, and the consequences of the fault so general, that corrective action was undertaken in this instance.

One quite general trouble disclosed by the charts was an ambiguity in our practices in connection with a specific type of system, where a lineup tolerance of ± 1 db. in a certain adjustment was allowed without any compensation elsewhere. Correction of these practices will remove this source of variability.

There is something about these $\overline{X}$ charts that a quality control man will spot immediately, the tendency of the points to fall above the center line, which is taken as zero. The averages tend to have a positive value, rather than the expectancy of zero.

This tendency has a strong annual cycle about it, too. Figure 5 shows the annual variation in the quarterly averages of the distributions of deviations in N and K Carrier.

N & K CARRIER
AVERAGE IN EACH QUARTER
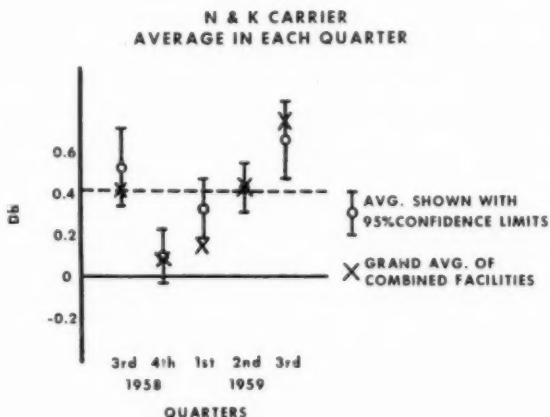
Fig. 5 - N & K Carrier - Variation in Quarterly Averages

It is not much different from the averages of all types of facilities. We have a great deal of information confirming this annual cycle for all kinds of facilities.

Insofar as N Carrier is concerned, we have found that this annual cycle can be accounted for by the residue of temperature variations that are uncompensated for by the automatic temperature regulation of the system, hence the further reduction of this variability should be a matter of system design, rather than maintenance adjustment.

However, we have not yet determined just why we should have a constant positive component of the quarterly averages. The most plausible explanation to date seems to be that, in lining up a trunk, a man likes to approach the objective from the lower side. He is rather reluctant to raise gains, and as a result tends to leave things, on the average, just below the specified gain.

In this application of control charts, to date, we have bettered our bogey with the expenditure of about 80% of previous effort. This is quite gratifying, but there is little doubt that adequate investigation of these quarterly average figures to get at the causes behind them, would yield us considerably better results.

<u>SUMMARY AND CONCLUSIONS</u>

I hope this story has brought out the following points with reasonable clarity:

1. The control chart method is applicable to anything measurable. It doesn't matter what type of product we are dealing with.

2. We don't have to wait to apply control charts until after we have got things in order. We can use control charts effectively and economically just to get things in order.

In conclusion, it might be well to emphasize the simplicity of application of the method. Given a certain amount of base-period data, the engineer can compute control limits and set up average and range charts for any group of facilities. The testboard man can select rational sub-groups of four, make measurements, and plot the average and range of each sub-group. If these values fall within the control limits, he takes no action. If either value falls outside limits he investigates. In most instances he will readily find the trouble, and take action to remove it. At the same time this action is likely to remove assignable causes from other facilities as well, since quite a number of such causes will be common to a whole group, not necessarily all represented in the sample. In a few cases where the testboard man cannot find the specific trouble, he should refer the problem to the engineer, rather than resort to a compensating adjustment. As troubles are found and removed, limits can periodically be tightened up to a limit of the system capability. Practically all the work is done at the testboard, by the testboard man; and the amount done can be adjusted to whatever is deemed to be desirable in view of the amount of trouble that is actually being experienced.

<u>REFERENCE</u>

ASTM Manual on Quality Control of Materials

MEASURING RELAY CONTACT EROSION

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Present day telephone systems employ large numbers of relays for switching, controlling and signaling purposes. Usage of such devices is, of course, not confined to the telephone industry. In the large majority of telephone applications, relay contacts are designed to last the entire life of the particular circuit unit involved. In a few situations, however, the type of contact load and frequency of operation result in appreciable wear from electrical erosion.

For a particular design of relay the extent of erosion will depend on a number of factors. The current density and inductive energy of the load circuit are generally predictable for a given design application. The number of operations to which a relay is subjected may vary from one location to the next. The length of lead between a contact and its load also affects contact life, and this factor is often highly variable. Environment, length of time between operations and certain mechanical adjustment conditions also have an effect on the erosion rate. Anticipation of all the interacting factors is a very complex problem from a design viewpoint.[1]

Depending on the number of customers served from the particular building, a telephone central office may contain from 50,000 to 40,000 relays, each with an average of 5 sets of contacts. The relays are components of functional equipment groups with varying operational requirements and rates of usage.

Under normal conditions, contact life up to 50 million operations can be expected of these relays. Their durability can usually be increased considerably by provision of contact protection in the form of a capacitor in series with a resistor to drain away the excess current. Such protection is used where it is economically justified, or in cases where circuit operation failures due to erosion would be particularly serious.[2]

About half of the relays in a central office will have usage not to exceed 50,000 operations annually. Thus with normal contact loads, they can be expected to have many years' contact life. On the other hand, there are groups of relays required to operate 1 to 5 million times a year. Also, there are some on which the usage runs to 25 million operations annually. Where there is an appreciable erosion rate on any of these relays, a considerable maintenance problem results.

NEED FOR MEASURING EROSION

In the period just prior to World War II a number of manual central offices were converted to dial operation using a newly developed switching system. Prior to actual operating experience it had not been possible for the designer to anticipate all the points where some contact erosion would occur. There were, of course, restrictions during the war years and an urgent need for plant expansion in the period following. These factors prevented for some time either addition of contact protection or consideration of circuit changes to alleviate erosion problems on equipment already in service.

The problems which did develop were in certain common control circuit equipments. There are from 100 to 300 such units in an office. Routine inspections to check for contact wear are quite expensive. Correction of individual cases as they are discovered in investigating trouble indications is very inefficient. Frequent maintenance operations in such complex circuitry is a potential source of man-made troubles. Available maintenance records in the offices involved did not show consistent experience for specific relay contacts.

Consideration of these factors led to the conclusion that variables sampling of a number of particular relay contacts in several offices should answer several questions. It was hoped that the wear rate could be estimated with sufficient accuracy to allow scheduling maintenance rehabilitation. If such schedules could be set up with an optimum balance between cost and risks of circuit failure, over-all maintenance operation would benefit greatly. If contact life could be determined, the economic justification for adding contact protection to existing plant could be evaluated.
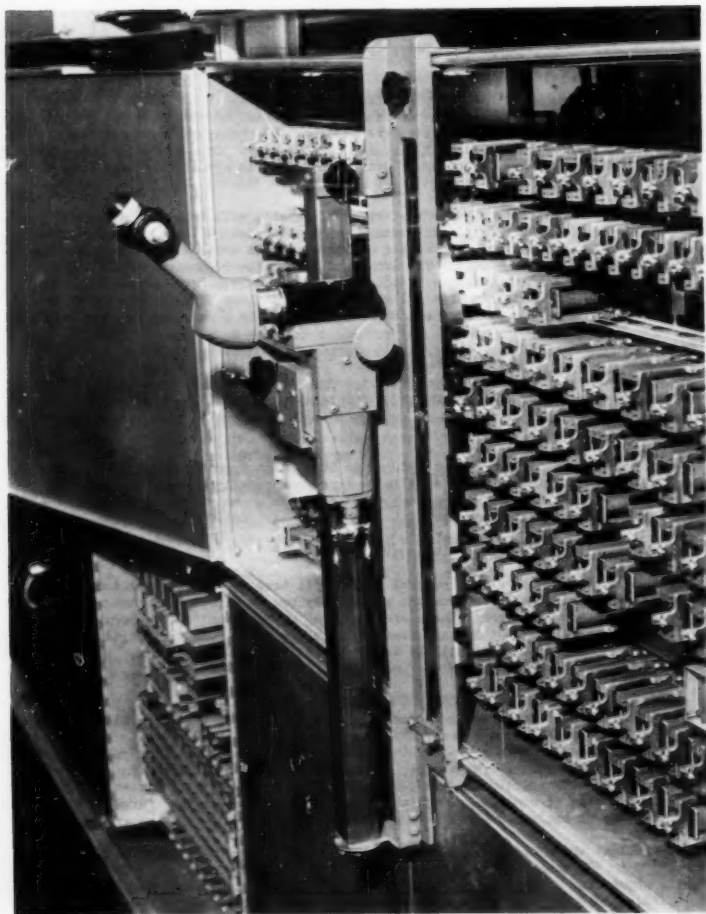
FIGURE 1 - MICROSCOPE IN POSITION FOR USE

The problem of measuring erosion on contacts of relays in plant by mechanical gauging seemed formidable. However, these contacts are accessible for visual examination from the front of the equipment. An arrangement for optical measurement of these dimensions, shown in Figure 1, was therefore assembled.[3] This employs an erecting, wide field microscope, 20X magnification, with eyepiece tube inclined 45°. The microscope has a field of 4.88 inches and a working distance of 3.5 inches. The Filar Micrometer eyepiece (12.5X), has a movable crosshair controlled by an indexed vernier dial. Illumination is from a small ring type fluorescent light designed for use in close-up photography. The gear for clamping the instrument on equipment cabinets and positioning the microscope in front of particular contacts was assembled from readily available components.

A pair of eroded contacts as seen through the microscope is shown in Figure 2. It will be noted that these are bar type contacts, with one placed horizontally and the other vertically on the actuating springs. Each scale division shown represents .020 inches and each of the 100 divisions on the crosshair vernier is .0002 inches. The crosshair is here at an indeterminate position for clarity of illustration. Dimensions are established by the difference between scale and vernier readings when the crosshair is set at the two ends of the dimensions being checked.

It will be noted that depth of erosion in the horizontal contact cannot be measured directly. Also, under some conditions of circuit load there is a transfer of metal from one contact to its mate. The particular contact which receives the "build-up" is determined by the circuit polarity and there will be a corresponding "hole" in the opposite contact. The criterion for serviceable contact life is the amount of contact metal remaining on whichever of the pair has the least. Such measurements must also begin at the bottom of any holes.

There result three different contact conditions, as diagrammed in Figure 3. The effective height of contact metal remaining can thus be determined by measuring three or four dimensions as shown. The type of erosion is determined by visual inspection and then only the appropriate dimensions are measured and recorded. In each case, measurements must be made with the contacts in both closed and open positions. Under two conditions, height of the vertical contact can be measured directly. In all other cases, the effective height is the difference between two measurements.

SAMPLING PLAN

Each telephone call originating in an office must be served by one of the common control circuits under discussion. These circuits are arranged in groups of ten. Any particular originating call will generally have access to ten such groups on a random distribution basis. In the older offices using this switching system, the lowest numbered idle circuit in a group of ten is always selected.

With this arrangement, the total call load is equally divided among the groups of ten circuits. Within the group of ten, however, the usage is heavily channeled to the lower numbered units. Circuit No. 1, for example, will handle about 25% of the total group load. The share of Circuit No. 5 is about 10% and that of Circuit No. 10 is only 0.7%.

In these offices, knowing the total call volume, it is possible to choose circuits with ten different degrees of use, and to estimate the number of operations each has experienced. For this stratified sample, five circuits were chosen at random from each of the ten usage choices. Particular relay contacts selected on the basis of maintenance experience were then measured in the 50 circuits comprising the total sample. Data were identified with the particular subsample of five.

Since later operating experience indicated that uniform circuit usage is more desirable, the entire load distribution plan is on a completely random basis in newer offices. In this case, all circuits in the office have experienced the same number of operations. The subsamples of five are not stratified, and were chosen on a random basis. Since the problem was essentially in the older equipment, relatively few measurements were made in newer offices.
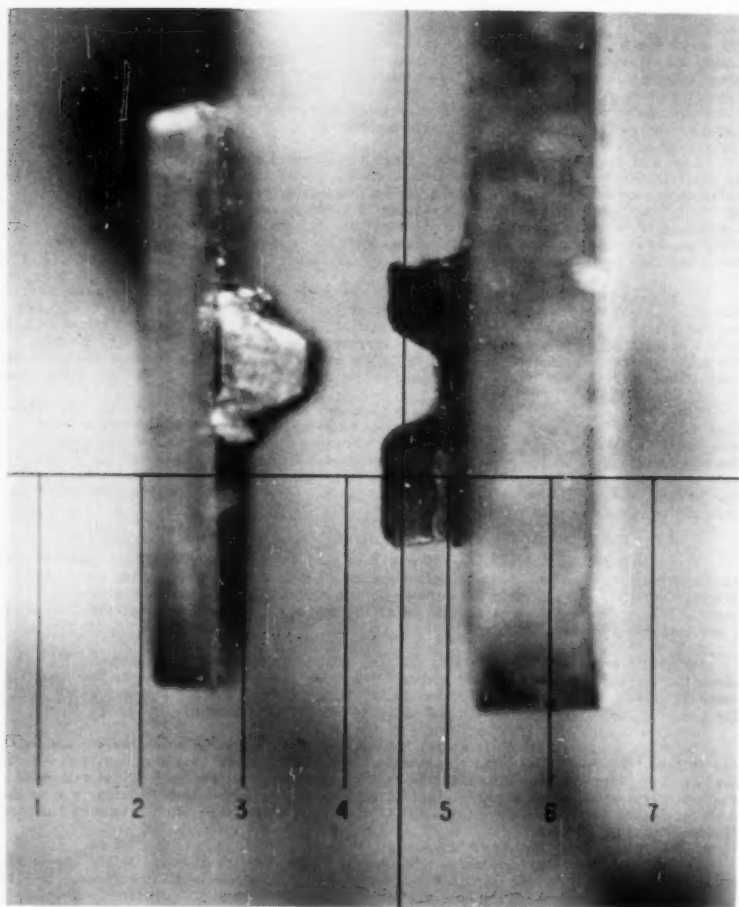
FIGURE 2 - ERODED CONTACTS WITH SCALE
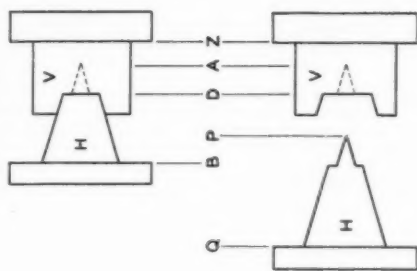
FIGURE - 3

MEASURING EFFECTIVE CONTACT HEIGHT IN PRESENCE OF EROSION

ESTIMATING CONTACT LIFE

For this purpose it appeared that three hypotheses should be tested:

1) That for a particular contact, the life is a straight line function of usage.
2) That the same contact would behave similarly in different offices.
3) That the data would be sufficiently homogeneous to enable an estimate of contact life to be made.

For the objective in mind, it seemed adequate to fit a regression line to the measured values by the method of least squares, and to make a visual comparison with the plotted points. However, with 50 points per office a scatter diagram of individual values would become quite crowded. For most of the measurements taken there are five contact height values for each of ten usage levels. By plotting means of these subsamples, the visual problem is made manageable. This also is compatible with the definition of the regression line, $y = a + bx$ as the estimated locus of average values of the dependent variable.

The theoretical assumption is that each measurement of contact height is an observation on a random variable which is normally distributed with constant variance about the mean value $a + bx$. An estimate of the variance of the observations is expressed by the equation

$$s_{y.x}^2 = \frac{\Sigma y^2 - a\Sigma y - b\Sigma xy}{n-2} .$$

This can be computed from the data used to obtain the equation of the regression line. From this value the theoretical 3-sigma limit of the distribution is obtainable. A plot of this limit would show at what point individual contact height measurements could be expected to approach zero.

EXAMPLES

From several dozen different contact situations measured, three examples illustrating different stages of wear are presented. It will be obvious that all theoretical assumptions of normality, constant variance and exact fit of the regression line are not met. Considering, however, all of the possible causes of variation inherent in the physical condition, it appears the data show behavior consistent with the hypotheses. From a practical viewpoint, an estimate of contact life can be made which is accurate enough for the purpose intended.
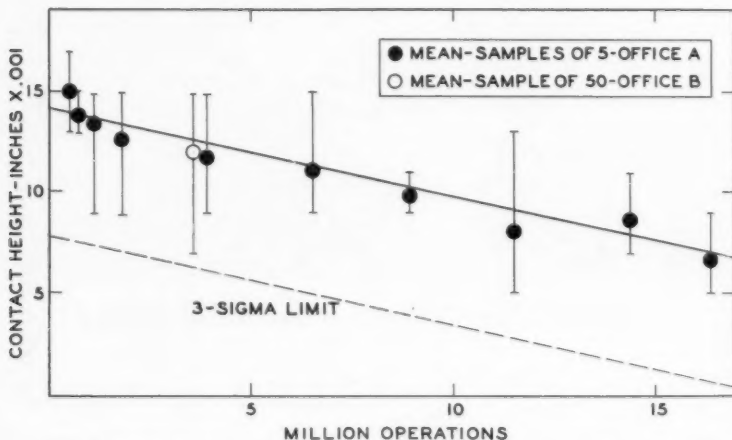
FIGURE 4-MEAN AND RANGE-CONTACT HEIGHT-RELAY "P"

In Figure 4 there is a case of moderate wear rate. The regression and limit lines were computed from 50 samples in a fixed choice office. The mean value is shown for each of the ten subsamples. The mean value of 50 measurements in another office with random usage is superimposed. The range of each of the sample groups is indicated by a vertical line. Fit of the regression line seems reasonably good, but the distributions are generally skewed. There was no observation outside the 3-sigma limit. At about 18 million operations there is the expectation of individual contacts worn through.
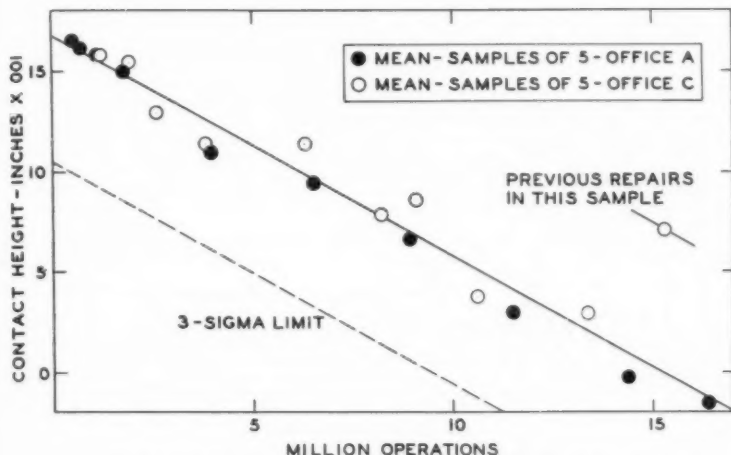
FIGURE 5-MEAN CONTACT HEIGHT-RELAY "Q"

The behavior of a faster wearing contact in two fixed choice offices is shown in Figure 5. Two interesting situations are illustrated. The subsample with the highest usage in office C contains some contacts which were replaced some time ago. The replacement date is not available in the maintenance records. On the surmise that this occurred at nine million operations, this sample would fit very close to the regression line. At that point, the 3-sigma limit indicates that individual contacts completely worn through could be expected.

Since this subsample is from a different population, it was excluded in determining the over-all characteristics. The regression line and variance were computed from the remaining 95 measurements in Offices A and C combined.

The two highest usage subsamples in Office A have averages which are minus values. Here is a case where a contact build-up has worn entirely through the contact metal of its mate and penetrated into the actuating spring. Normally these cases would have been replaced some time ago. However, circumstances had delayed the rehabilitation in this office. Even in this condition, the contacts remained reliable enough that emergency treatment was not necessary.

For clarity of the illustration, ranges of the subsamples are not shown in this Figure. The variance, ranges and general pattern of the distributions are comparable to those in the previous case.

Extreme wear rate is illustrated in Figure 6. Here there are only nine subsamples in two offices which have not been subjected to contact replacement. Since wear-through could be expected at about four million operations, the highest usage choices have had replacements three or four times. The maintenance philosophy has been to treat such cases a choice at a time as wear-through develops. The averages of these treated choices are therefore widely scattered and have been omitted for clarity of the illustration. Visually they appear to conform to about five regression lines parallel to the one computed from the 45 lowest usage measurements. After seeing these results, it was obvious that contact protection should be provided for this case.
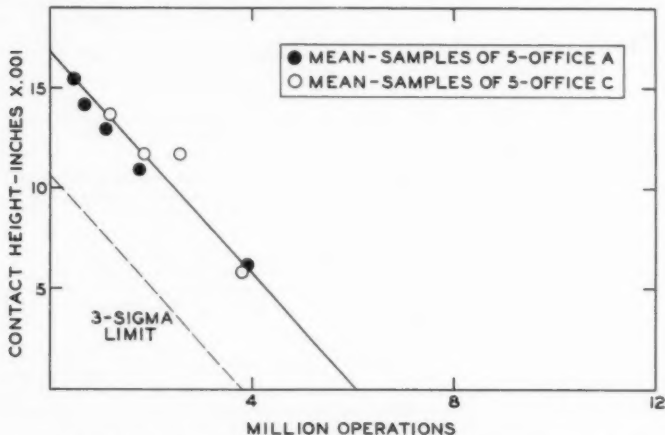
FIGURE 6-MEAN CONTACT HEIGHT- RELAY "R"

CONCLUSION

Optical measurements of erosion on relay contacts in service provided data for statistical analysis. Where particular contacts with various usage levels were sampled, a regression line could be fitted to the data. Computation of a 3-sigma lower limit from the sample variance allowed an estimate of when individual contacts completely worn through could be expected. The data indicated good conformance to a straight line wear rate and compatibility of behavior in different locations where the same type of equipment is in use.

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NEW DEPARTURES FOR OPERATIONS PROBLEMS

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Standard Oil Company, (New Jersey)

WHAT IS OPERATIONS RESEARCH?

Operations Research is an advanced analytical approach which can aid long term business planning or the solution of daily operating problems. Its main objective is to provide management with a scientific analysis of the "cause-and-effect" relationships of a specific situation. It is then possible for them to blend this scientific information with such intangibles as general business conditions, politics and psychology to arrive at a final decision.

Operations Research can be considered as a method of expanding the number of factors that can be considered simultaneously when arriving at a decision. For years, assistance of this type has certainly been the objective of consultants and of various engineering groups. However, the major difference between most of these and Operations Research is in terms of the approach and the techniques used. The characteristics of Operations Research are that it:

> Applies the "scientific method" to the solution of business problems more rigorously.
> Uses advanced mathematical, statistical and computer techniques to aid analysis when necessary.

Let us consider these points in greater detail.

WHAT IS THE OPERATIONS RESEARCH APPROACH?

The exact steps followed in investigating a particular problem certainly depend not only on the factors to be considered, but also on the type of answer desired, and the time available. However, the approach outlined below, as an example, is typical of that which has already been used to solve several Operations Research problems. These five steps will be described in turn:

1. Define problem and set limits and objectives.
2. Collect data and analyze.
3. Develop mathematical model of the situation.
4. Test the accuracy of the model.
5. Use model.

Although the O.R. approach is very general and can be used for many problems, the discussion revolves about a terminal planning problem to aid continuity and understanding.

1. Define Problem and Set Limits and Objectives

While it may appear to be obvious, the thoroughness and clear thinking used in this first step often can determine the eventual success of the project. Once having looked into the matter of what is required and the ability of Operations Research techniques to handle the job, boundaries must be defined so as to determine the scope of the project. It is here that preliminary investigations and conferences with management take place. Once the problem is clearly defined and the scope set, the other steps can follow in sequence.

A typical terminal planning problem might be stated as follows:

> Develop a planning tool that would depict comprehensively the numerous variables involved in the terminal operation so as to assist in determining (1) the "best" number of berths and (2) most efficient amount of terminal tankage.

2. Collect Data and Analyze

In a problem of this type, extensive interviews of terminal personnel must be made to determine operating characteristics, tank and piping arrangements, and special problems associated with the terminal operation. Data would also be analyzed to determine the characteristics of tanker arrivals, berthing times, and loading rates.

3. Develop Mathematical "Model"

This step (often the most difficult) is concerned with developing some sort of "model" which will represent and tie together the various factors involved in the terminal operation, so that their cause and effect relationship can be determined. ("Models", referred to in Operations Research phraseology, generally take the form of mathematical equations and/or computer programs - they are different in nature but analagous to

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to "pilot plants" of refinery or manufacturing processes.) The next section describes
in more detail the various types of models and how they can be used and constructed.

The important characteristic of a model is that changes introduced to the model
must produce much the same effect as when these changes are introduced to the real oper-
ation. For example, if the model indicates that an increased loading rate of 5000 B/H
reduces tanker waiting time by 3 hours per day, then in actual practice substantially
the same reduction must occur.

The main advantages of having a mathematical or computer model are:
1. The effect of various changes can be studied without disrupting operations
    or incurring unnecessary construction. For example, the effect of reducing
    loading rates could be studied without incurring the delays that might result.
2. The answer can be obtained in a shorter time than if actual operating data
    had to be collected and analyzed.
3. The model can easily be used to see how the business would react under a
    very wide variety of conditions.

4. <u>Test the Accuracy of the Model</u>
This step is one of the most important. It consists of determining how well the
"model" expresses the cause and effect relationship of the variables actually involved
in the operation. In this case of a marine terminal, one could feed into the computer,
say - the throughput, arrival and loading conditions of an historical period and compare
tanker waiting hours obtained through the model against those experienced in actuality.
If close agreement is not obtained, the model itself must be redesigned. It is this at-
tempt to approach realism and to avoid unrealistic assumptions that often leads to mod-
els of some mathematical complexity.

New models are being developed continually to aid in solving many problems other
than the terminal problem described here. Typical problems in the marine field being
considered by Operations Research are:

AREA	TYPE OF QUESTIONS ANSWERED
Inventory Control	How often should inventories be replenished? What is the most economic amount to order?
Terminal Tankage	What is the best amount of terminal tankage, consider- ing customer satisfaction, capital tied up, and tanker waiting charges?
Tanker Scheduling	What is the lowest cost method of scheduling a fleet, considering requirements, tanker positions, and tanker operating costs?
Tanker Allocation	What is the best way to allocate various sized tankers to different trades, considering operating costs, the length of haul, demand, and turnaround?
Tanker Coverage	Considering future requirements and chartering costs, what is the best "mix" of owned and chartered ships of various types?
Tanker Size	What is the most efficient tanker size considering oper- ating costs, tankage requirements, terminal modifica- tion costs, and fleet scheduling?

5. <u>Use Model</u>
The developed model can be used with confidence to study the effect of changes in
operating practices or the physical facilities of the terminal. Graphical or other nu-
merical representations can be constructed showing the effect of throughput, number of
berths, and amount of tankage on tanker waiting time. The job is not complete until re-
sults have been translated into meaningful and practical form. (See Figure 1).

This report, in the form of a graph, shows management that with only one berth a-
vailable at the terminal, waiting time would increase very rapidly when the terminal
throughput reached a certain point. The effect of a second berth is also shown. (For
a specific terminal, the actual magnitude of the variables would, of course, be indi-
cated.)

FIGURE 1
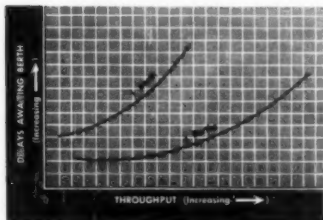
The important points to note in this process are (and these are not limited to the terminal problem described above, but are true for most Operations Research studies):

A model is developed - using any mathematical or computer technique required - which depicts the cause and effect relationship of the variables considered important to the problem. The model is then tested. This is where the "scientific" method comes into play.

To be sure, in actual practice, the approach may be modified to adjust for the size, scope and economic consequences of any particular problem. In some cases, for example, the collection of data and its analysis are sufficient; in others, a more thorough economic analysis may be required.

What Are Some Examples?
Because of the basic importance of models in really understanding Operations Research and how it is performed, alternative models which might be used to solve a particular problem are described in the pages that follow.

PROBLEM
Consider, as an example, a very simple problem:
    Problem: At a marine terminal having only one tanker berth, tankers arrive
                to load crude. What effect will the addition of a second berth
                have on ship waiting time?

This problem as stated, has been simplified for purposes of illustration. However, the basic problem is of real importance to terminal planners. They must know how many berths to build so as to handle the anticipated traffic.

On the one hand, building too many would be extremely expensive and, on the other hand, building too few (thus incurring excessive tanker waiting time) would also be extremely expensive.

Conventional methods of solving this problem often center about a "berth occupancy" or "use factor." The results of using this basis have not always proved to be satisfactory. Operations Research has been able, through the methods outlined below, to arrive at more accurate answers than hitherto possible. It must be stressed, again, that this example is greatly simplified, so as to describe more easily some of the various types of models used in Operations Research.

SOLUTION 1. BY FORMULA MODEL
The formula below was developed with the use of advanced mathematics. It will hold true if the following conditions are met:
    1. A large number of different ships use the terminal.
    2. The tankers arrive without any specific pattern.
    3. All vessels that arrive are loaded on a "first-come, first-served" basis.
    4. Variations in time required to load follow a particular pattern.

If these conditions are met, the average time that a tanker will be required to wait can be determined by solving the formula below. (One of the contributions of Operations Research is the developing of formulae to fit business situations.)

$$W = \frac{(\rho c)^{c+1}}{\lambda (c-1)! \sum_{n=0}^{c} \frac{(\rho c)^n}{n!} [(c-n)^2 - n]}$$

W =   Average Waiting Time per Ship in days.
    =   Average Tanker Arrival Rate, Ships per Day.
    =   Average Time to Load, Ships per Day for One Berth.
c =   Number of Berths.
    =

    The effect of adding a second berth on ship waiting time can be determined by sub-
stituting the proper values into this formula model, (first with c = 1, then with c = 2).
Although this is relatively easy to do, the question still remains as to whether this
formula is a good "model" of the terminal. The answer will be yes, only if the assump-
tions concerning the "pattern" of arrivals and tanker loading used in developing the
formula are met at that particular terminal.

    Actual experience has shown that this formula represents adequately some terminals.
In other cases a formula may not fit. For instance, if additional variables are intro-
duced, (such as restricted anchorage space, limitations on night navigation, docking on-
ly at certain stages of the tide, etc.), it would be very difficult - perhaps even im-
possible - to develop a formula model which would fit such an involved situation. Alter-
native methods of solution are Replication models and Monte Carlo models.

SOLUTION 2. REPLICATION MODELS

    The Replication model works this way: It reviews historical data to determine the
sequence and timing of events so as to use the past data as an input to a system and then
note the numerical value of an item required for analysis. To clarify this, suppose
that the observed data on past ship arrivals and loading time at the terminal were as
shown in Figure 2. It can be seen in this simple example that the ESSO SANTOS arrived
at noon on August 2, waited until midnight to start loading at Berth 1, and finally de-
parted before noon on August 4. The average time a ship spends waiting at the terminal
can be determined easily by adding and averaging this past experience. Theeffect of a
second berth could be determined by using the same arrival and loading data and allocat-
ing the ships to either one of the two berths as they become available. This new allo-
cation, incorporating a second berth, is shown in Figure 3. In this case, it can be
seen that when the ESSO SANTOS arrived it could have gone immediately into Berth 2. A-
gain, one can estimate the time spent waiting at the terminal and hence evaluate the ef-
fect on tanker waiting time of building a second berth. The nice thing about this type
of model is that it is not necessary to make any assumptions about the pattern of arriv-
als and loading. Actual past occurrences are used to provide this information. If it is
likely that the same pattern will prevail in the future, and if all pertinent variables
can be taken into consideration, then this approach can be extremely useful.

    When neither the Formula Model nor the Replication Model apply, the Monte Carlo mo-
del may provide the solution.

FIGURE 2

OBSERVED TANKER ARRIVAL AND LOADING DATA
(1 BERTH)

TANKER	Arrival and Loading Data								
	Aug 1	Aug 2	Aug 3	Aug 4	Aug 5	Aug 6	Aug 7	Aug 8	→ etc....
Esso Cube									
Esso Santos									
Esso Richmond									
Esso Montevideo									
Esso Ponce									
↓ etc....	= Time at berth		= Time waiting						

FIGURE 3

MODIFIED ARRIVAL AND LOADING DATA (2 BERTHS)									
TANKER	Modified Arrival and Loading Data								
	Aug 1	Aug 2	Aug 3	Aug 4	Aug 5	Aug 6	Aug 7	Aug 8	→ etc....
Esso Cuba	BERTH 2								
Esso Santos		BERTH 2							
Esso Richmond			BERTH 1						
Esso Montevideo									
Esso Ponce									
↓ etc....									

SOLUTION 3. MONTE CARLO MODEL

In the above example, the actual arrival and loading data observed were used as a basis for arriving at an answer. Under certain circumstances, where, for instance, there may be no past experience to draw upon, as would be the case in planning a new terminal, or in other cases where extreme complexity is involved, it might be better to develop a hypothetical or fictitious pattern of arrivals and loadings. The result of using this hypothetical pattern, which may be suggested by experience at similar terminals, will be valid if this pattern has the same underlying properties as the anticipated future arrivals at the terminal.

For example, one could start by representing the time between tanker arrivals by the method used in Figure 4. This figure shows in a convenient way the probability of any particular "time-between-arrivals" happening. (This type of diagram is called a "Probability Distribution.") In this case, for example, it states that in approximately 60 cases out of 100, the time-between-arrivals is 12 hours, etc. (Twelve-hour intervals were used in this case; in practice any interval could be used.) At this point the percentage of time that an event occurs is known, however the sequence (e.g. 12,12,24 or 24,24,12, etc.) of those events must be determined. One way of generating a hypothetical sequence of arrivals would be to first let the numbers between 1 and 60 represent a period of 12 hours between tanker arrivals; the numbers 61 to 90 represent 24 hours between arrivals; and numbers 91 and 100 represent 36 hours between arrivals.

FIGURE 4

PROBABILITY DISTRIBUTION OF TIME BETWEEN ARRIVALS
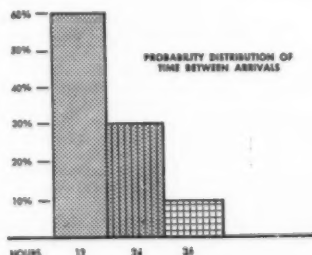
Thus, the numbers from 1 to 100 represent the probability of any particular time between arrivals and they conform to the situation shown by the probability distribution diagram. Having assigned these numbers to represent a certain time between arrivals, the numbers can then be drawn by a random chance - say, out of a hat - to generate an arrival pattern. If, for example, the number 47 were drawn, that would indicate a "time-between-arrivals" of 12 hours. If more numbers were drawn the pattern of arrival in Figure 5 might be obtained. In this case, for example, the initial arrival time (an assumed time used to provide a starting point) was 12:00 on August 1, and the time to the next arrival was 12 hours. This places the next arrival at 24:00 on August 1, etc.

Just as in the Replication model, to solve the problem it is necessary to know both the tanker arrival time and time at berth. The time required to load each tanker could also be determined by sampling at random from a probability distribution of loading times.

This being done, one has really generated a body of tanker arrival and loading data which can then be analyzed in much the same manner as that used for the actual historical data by the Replication model (Figure 3).

The use of chance is justifiable providing a large number of samples are drawn at random (in practice, enough to simulate at least a year's operation). The important thing to bear in mind is that if the model is correct the combined effect of all arrivals as generated by chance will be very nearly the same as the combined effect of all arrivals occuring in actuality. When viewed in this manner, it becomes apparent that the particular arrival time assigned to any one particular ship has no bearing on the final answer. Only the combined effect is important. Electronic computers can generate a year's pattern in a matter of minutes. Consequently, extensions of this type of approach have proved to be very valuable in the actual analysis of terminal problems at Esso Pet's Fawley Terminal and Creole's Lacustre Terminal.

It should be noted here that a model of an operation need not involve a computer program - in this example, a formula, capable of being solved manually, might suffice. The need to translate a model into a computer program depends on its complexity and the use to be made of it. The computer is only another tool to be used when advantageous.

FIGURE 5

GENERATED TANKER ARRIVAL PATTERN

(ASSUMED STARTING TIME: 1200, AUGUST 1)			
Number Drawn at Random	Time Between Arrivals	Time of Last Arrival	Arrival Time
36	12	1200, Aug 1	2400, Aug 1
80	24	2400, Aug 1	2400, Aug 2
25	12	2400, Aug 2	1200, Aug 3
31	12	1200, Aug 3	2400, Aug 3
etc....			

TYPICAL FACTORS SPECIFIED AS INPUT

Arrival Pattern of Tankers
Tanker Sizes
Tanker Loading Rates
Berths
Berthing Time
Size and Crude Allocation of
   Each Tank
Fill and Suction Line Manifolding
Crude Metering Facilities
Crude Production Rates
Pipeline Pumping Capacity
Field Tankage

TYPICAL OUTPUT OF MODEL

Tanker waiting hours by class of
   vessels and caused delay
Required changes in tanker alloca-
   tion slates
Crude shut in
Crude degradation required
Inventory level, all grades
Number of times a tank is swung
   over from one crude to
   another
Berth utilization
Line utilization

Models can be used to solve many complex problems where numerous variables are involved. By way of example, the above are typical of the factors which were actually considered in one Monte Carlo model. (The reader will recognize that the problem is much more advanced than the one described above.)

WHICH MODEL TO USE?

The problems discussed above have been fairly simple, the approach straightforward. In reality the way of approaching a problem and determining the type of model to use depends on the problem or business to be simulated (size of operation, number of variables involved, amount of variation present, day-to-day operating or planning use?), the amount and reliability of data (sufficient to study past behavior, changes and inter-relationships?), the type of answer desired (a "best" solution, a case study tool, or useful graphs?), the availability of computing facilities (can complex formulae be easily evaluated?), and the suitability of various mathematical formulations (allocation problems solved by Linear Programming ; inventory problem-solved by Markov Theory; Congestion-solved by Queuing Theory; Scheduling problem-solved by Network Analysis; Competitive problem-solved by Game Theory; etc.)

The essential point is that changes introduced to the model must produce nearly the same effect as if they were introduced to the business situation itself.

SUMMARY

In summary, Operations Research is an analytical approach which can often aid in the solution of business planning and operating problems. The chief charteristics are:

A scientific analysis is made of the cause and effect relationship of many of the important variables in a problem. This analysis tends to narrow the range of "intangibles" that have to be considered by management in making a decision.

The latest advances in mathematics, statistics, and computer technology are used to develop a model of the business. Recent advances in these fields make the approach especially useful when there are many variables to consider and/or these variables, themselves, vary over a wide range. Specifically, modern electronic computers can solve in a matter of minutes mathematical problems which, when attempted by hand, might take days.

The approach is often concerned not only with getting "an answer" to a problem (many answers may be feasible), but also a basic understanding of the operation and the variables involved so that the "best" answer can be obtained.

Although this is a relatively new field, many successful applications have already been made. As time goes on, people working in Operations Research are developing both a firmer understanding of the nature of business problems, and of the capability of various types of models to cope with the problems presented. The result of this activity has been an increased ability to aid management by providing factual, objective analyses as a basis for policy-making decisions.

THE HUMAN EQUATION IN QUALITY CONTROL

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Always, we come back to the need to control people if we're going to control quality. And as science and technology become more and more the handmaidens of quality production, so does the human equation appear very often to be more and more recalcitrant! Perhaps this isn't so -- perhaps science and technology have not lessened our demands on people as much as we're inclined sometimes to think they have -- but we'll come back to this later.

I'd like to stay for a moment with this idea of "controlling people. Taken literally, the term represents a dangerous false assumption. We don't "control" people in any direct way. When we attempt it, we're likely to run into those frustrating experiences that encourage the use of such adjectives as "stupid", "stubborn", "hammer-headed", "insensitive" -- but you can finish out the list. Most of us have already discovered that if we wish to change someone's behavior, our best bet is to change certain aspects of the situation in which he lives and works, to his interpretation of which he responds. If he moves in the direction we wish him to go, as a result of our "control", it's because we have managed to make a significant alteration in his life situation as he sees it.

Controlling human behavior is not merely a matter of introducing a significant change, of either a positive or negative nature, into an individual's life situation, however. Let me recall the phrase we just used: "as he sees it". Each of us looks at the world through a scanning glass that's polarized and to some degree distorted by feeling and emotion, value judgments, and the indelible traces of past experience. The individual whose behavior we wish to change does not respond directly to the situation we have recast any more than he responds directly to us. He responds to his interpretation of what he sees. He may not see what we wish him to see, or if he does, he may quite possibly attach a meaning to it that we never intended.

It may be necessary for us to help him increase his sensitivity in one area and reduce it in another, help him re-evaluate the meaning of his past experiences, and help him modify his value judgments before the desired change in his behavior comes about. Having done all this, we may not find it necessary to introduce change into his environment at all -- the desired stimuli may always have been there, but either he has not seen them, or he has been interpreting them incorrectly. Let's remind ourselves that even in this case his changed behavior remains a function of his perception of his situation as he sees it.

THE SOCIAL CLIMATE FOR QUALITY CONTROL

I'm sure all of us will agree that the proper way to achieve high quality is to make quality production a source of job satisfaction to the man on the production line. A number of people are inclined to believe this ought to come about "naturally". In terms of our comments of a moment ago, they feel that the average work situation already embodies all the necessary positive motivation for high quality production; and that when the worker fails to respond, it is due to some inadequacy on his part. "Pride in workmanship is a thing of the past" they remark sadly. The typical production worker today, they tell us, far from having any real interest in quality, is concerned only with doing work that's just good enough to get by.

The truth of the matter is that there is probably a higher proportion of people doing high quality skilled work today than there ever was -- for in recent years we've added the technician to the "old aristocracy" of the craftsman, and we haven't reduced the proportionate number of the latter in the work force. What has happened is this. As a nation, we've so increased our demands for quality production during the past two decades that we can now meet them only through mass production; and we have begun to ask the semi-skilled worker, the man on the assembly line, to pay the same attention to detail and quality that we formerly expected only of skilled workers.

But we can't expect that he will do it "naturally". In the first place, he has not had the benefit of the rigorous training of the craftsman that results in a sense of "profession" and built-in standards of quality which demand satisfaction from within himself. In the second place, assembly-line work does not involve him sufficiently on

a personal basis for production to be naturally a matter of "personal" concern to him.
In the third place, while we have actually increased our demands for quality workman-
ship, we have tended to decrease the emphasis on it that reaches the public -- which
includes our semi-skilled worker.

This last item may seem paradoxical, but there are explanations for it. In many
cases nowadays, the components that call for quality workmanship in a consumer goods
item are so complex that we're afraid the buying public won't understand what we're
talking about if we emphasize the quality side of the picture. We dwell on ease of
operation, styling, and emotional appeals to sell our product for us. Quality is as
important as it ever was; perhaps more important, for customers demand reliability from
an increasingly complex product -- but we don't stress it in the consumer goods market.
We obscure it through emphasis on style change that is intended to make the customer
unhappy with what he has and eager to discard it in favor of what is perhaps the same
basic product dressed up in a new package. We should not be surprised then if our semi-
skilled worker, an important member of the consuming public, appears to be more con-
scious of the "wrapping" than of the quality implications of what's inside.

All this by way of pointing up the fact that if we wish our production workers to
"build quality into the product" for us, we've got to do more than tell them what we
want and rely on an inherent and natural tendency on their part to give it to us.
Neither their individual backgrounds, mass production methods, nor the prevailing
social climate encourage a "natural" interest in quality production. So the "human
relations challenge" in Quality Control is this:

> "How can we make the production worker quality-conscious?

This is a question of motivation; so let's turn our attention to this topic for
a few moments.

THE BASIS OF MOTIVATION FOR QUALITY

"Motivation" is a word we're likely to use without being sure other people under-
stand it to mean the same thing we do; so let's get ourselves in step with a definition.

> Motivation is a socio-psychological mechanism that "moves" us to satisfy a certain
> need in one way rather than another, in such a fashion that each step toward satis-
> faction is a meaningful step.

Translating this definition into the quality control picture, the answer to the
question we raised above becomes quite obvious.

> We make the production worker quality-conscious by making quality meaningful to
> him, a matter of importance, as a part of his progress toward the satisfaction of
> a basic personal need.

As the basic need concerned, let's establish "job satisfaction" -- which we will
take to mean not only the worker's paycheck, but other less tangible returns he may
ask of his job. These might include
  1.   A feeling that he is "part of the team", arising out of his knowledge that
       he's doing useful work that is adequately recognized.
  2.   A sense of understanding and being understood.
  3.   A sense of self-respect.
  4.   Work that is "interesting".

Obviously, when these and other satisfactions are lacking or are difficult for
him to obtain, his paycheck becomes overwhelming in its importance to him. It has to
substitute for all the rest. Perhaps it's not quite so obvious -- but when we in man-
agement assume that his paycheck is all that matters to the worker, our assumption is
quite often "proven" by his behavior. Not because the assumption is basically true --
but because simply by virtue of having made it, we frequently fail to provide him with
the opportunity to realize other satisfactions!

POSITIVE AND NEGATIVE APPROACHES TOWARD MOTIVATION FOR QUALITY

We can choose between two basic approaches in making quality a matter of personal
concern to the worker as he seeks job satisfaction.
  (1) We can impose "quality" as a hurdle, a barrier, between the worker and his
       paycheck.
In doing this we are, by implication, assuming that his paycheck is all that
really matters to him. We're making quality important to him by introducing it as a
threat that must be overcome if he is to reach an ultimate goal of personal importance.
The "control" -- the motivation for quality -- remains almost entirely external to the

worker. Any lowering or withdrawal of the "inspection hurdle" will result in an
immediate flood of poor quality work. It's an expensive method, since it requires
almost constant surveilance of worker activity; and it can never be completely effec-
tive since (as we've already noted) the employer no longer has sufficient control over
the worker's chance to earn a living to give an economic threat much more than nuisance
value.

And since we've implicitly established his paycheck as his only important goal,
there's a good chance that when we use this method we will fail to provide the worker
with other opportunities for job satisfaction that might encourage quality production
in a more positive way.

(2) We can establish "quality" as a positive rather than a negative factor in
the worker's mind, encouraging him to look upon it as a stepping stone toward, rather
than a barrier in the way of, job satisfaction. We may even be able to get him to see
it as representing one aspect of job satisfaction in itself!

Under this second method, we hope we may get the worker to "internalize" quality
standards so thoroughly that they become as much as part of his "self" as his prefer-
ence for fried chicken over snails, or his political allegiance. We want him to turn
out quality work as a matter of "self" satisfaction, even though he's aware that it's
not going to be inspected.

I'm sure we'll all agree that the second method is the preferable one. Its advan-
tages are obvious -- "100% inspection", a monitoring rather than a "policing" role for
Quality Control, a generally better morale climate for production, and so on. But
agreeing that a method is desirable doesn't get it into operation. We're still faced
with the question we raised a few moments ago -- how do we go about establishing posi-
tive motivation toward quality as an integral part of the make-up of a production
worker?

SOME STEPS TOWARD POSITIVE MOTIVATION FOR QUALITY PRODUCTION

We'll merely note for the record that production management has considerable res-
ponsibility in this area as well, and forget about it. What can we in Quality Control
do, both directly and in "backing up" Production, toward making quality appear to the
worker as a stepping stone rather than a barrier -- as a goal in itself, rather than
an obstacle to be surmounted on the way toward reaching a primarily economic objective?

Some suggestions follow. They are not all-inclusive by any means. Their practical-
ity may vary from one situation to another. But perhaps they will at least point us in
the right direction -- or encourage you to look for the right direction in the process of
refuting them!

1. **Let's keep Quality Control in its proper functional perspective.**

As staff people, we must guard constantly against the inevitable tendency to think
of our delegated function as our principal objective. We want to be considered "part
of the team" -- then let's think that way, and what's more important, be sure our people
think that way. The Quality Control executive or engineer is at a level where it's not
too difficult for him to see the "big picture", and realize that Quality Control is
only a part of it. We tend to forget how difficult it is for our people in the lower
echelons to maintain this perspective.

But if we are successful in reaching and maintaining an "end-product orientation"
for ourselves and our people down the line, we will have taken the first and most im-
portant step toward selling the production worker on quality as a personal goal. If
we can convince him that we really think of ourselves as helping him to build a quality
product, we will have identifed ourselves with him. We will have set up the rapport
that must precede anything else we may want to accomplish in a positive direction.

2. **Let's establish realistic standards for quality.**

We're going to convince the worker of the importance of quality workmanship only
when the standards for judging it are realistic from two points of view:
   (a) The functional need for them.
   (b) The physical possibility of meeting them.

We're going to have to justify quality standards to the worker in terms of the
"sense" they make to him. This is tough enough even when they're necessary. Let's
never find ourselves in the unenviable position of trying to justify standards that
are actually arbitrary and unreasonable, merely to "save face". We're not likely to
succeed in the attempt; and we'll have created an atmosphere of suspicion and distrust
that will cast doubt on the remainder of our standards that are functionally necessary.

Faced with standards that are physically impossible to meet, the worker is not likely even to come as close to them as he can. More usually, he will stop at a level of quality that is less than he can turn out, simply to emphasize to us how impossible the standards are. On the other hand, when it is merely difficult to achieve them, but we have convinced him of the functional necessity for doing it, the worker can regard high standards as a challenge, and our insistence that he meet them as an important and necessary part of production.

I'm aware that economic considerations alone are likely to keep us from deliberately setting standards higher than they need to be. But I'm also aware that we're not always as sure as we should be how high they do need to be, and the tendency is to "play it safe", particularly if we happen to be an hourly rated inspector. When the production worker asks "how much is enough?", we ought to be in a position to answer him on the basis of sound reliability research.

3.   Let's educate the worker for quality.

It isn't enough to establish realistic quality standards from a functional point of view. We've got to explain to the production worker WHY they are functionally necessary. Though the quality of the end product may not be important to him as the eventual user, he possesses the human ability to identify with the user; and through this empathetic relationship quality can become a matter of concern to him even from the standpoint of use. This is one of the most important of the ways by which he "internalizes" quality standards.

If, for reasons which we must admit are not completely under the influence of Quality Control, the worker identifies in a positive fashion with the company itself, we have a second road to "internalization". As we are able to justify the need for quality from the company's point of view, he makes it a need from his point of view. While this possibility is a function of company-employee relations in general, it becomes apparent that whatever Quality Control can do to elevate the general level of morale in the plant will have a direct bearing on the quality of output. In this respect we ought also note that deliberately poor quality is one of the weapons an employee may use in "fighting back" at a company when he feels himself to be poorly treated.

This education of the worker as to the functional need for quality ought to be a part of his initial orientation, of his initial and subsequent formal training, and a continuing on-the-job process. It is best handled by the Training Department and the "line" -- with the backing and cooperation of Quality Control, of course -- not necessarily because these people can do it better, but because we want to impress on the worker the fact that quality is a matter of importance to everyone, not merely to the people who have been delegated the specific function of "controlling" it. Quality Control people must be prepared to do an "ad hoc" educational presentation at any time, however, as it becomes necessary or desirable to explain to people in Production the "why" that is behind a particular set of quality requirements.

4.   Let's train for quality

If Quality Control is going to maintain the respect of the production worker, the inspector has to know considerably more about the component and its use than is needed merely to compare it against a set of arbitrary standards. Even when inspection is a "go-no-go" proposition, he must be able to justify the standards in terms of the function of the component. When inspection is not this "simple", and borderline cases are encountered that call for the exercise of judgment, his decision will be accepted as proper only when he can go beyond "what the book says", and explain it in terms of the component in its total context of function and use.

He will be called on not only to exercise judgment himself, but to recognize its capable exercise by others. Most difficult of all, he will need to recognize his own limitations, and know when to call in a superior or a staff man who is better qualified than himself to pass on a case in the "gray" area.

Though Quality Control is not responsible for the training of production personnel, it can make its job later on considerably easier by cooperating in every way possible in the initial training process. Here again, a "behind-the-scenes" role is best from a strategic standpoint, but the occasional appearance in the training picture of an inspector or Quality Control representative who can demonstrate that he and his brethren are in the plant to help the worker rather than hinder him can pave the way for positive relations later on at the workplace.

It is through training of the production worker, incidentally, that a third avenue is opened by which he can "internalize" standards of quality. He will never incorporate them as a part of the disciplinary mechanism of his "self" if he cannot

achieve them. Quite the contrary — in order to protect his image of himself as competent and capable, and to avoid painful self-criticism, he will convince himself that they are arbitrary, unrealistic and unimportant. But once he has acquired sufficient skill to work to standards comfortably, he is in possession of a very effective "ego-building" device. If other aspects of his work situation are handled properly, the achievement of quality production can become a job satisfaction in itself.

5. Let's maintain rigorous enforcement of reasonable and uniform standards.

In the final analysis, the worker believes what he sees rather than what he hears. Unless Quality Control itself demonstrates that it believes quality to be of sufficient importance to call for rigorous and uniform enforcement of the standards it has established, we can't expect the worker to get very excited about it. Let's make this clear— we have not been recommending a "soft" attitude on the part of inspection. Reasonable, yes; but because of the very reasonableness of the standards we have established, because of the very reasonableness of the standards we have established, because of the education we have sponsored with regard to the need for them, and because of the training we have provided for their achievement, we cannot only dare to be but must be unyielding in our demands that they be followed in every particular as we have set them up.

Lack of uniformity in application of quality standards not only weakens our case as we plead their necessity; it destroys the effectiveness of the whole approach we've been suggesting. We want to build quality into the product rather than inspect it in. This can be done only when the importance of quality is consistently and uniformly emphasized all along the production line, rather than merely at certain designated inspection points.

6. Let's get our people "snapped in" on human relations.

We started out with the premise that Quality Control is essentially concerned with influencing the behavior of people. We've emphasized that this is effected not by exercising "control" over them directly, but by bringing about certain changes in the situations to which they respond. We want to do this in such a fashion that it results in a realignment of their personal value systems -- so that, in effect, they themselves generate a "climate" that is favorable to the production of a quality product.

From this point of view, the value of sound training in human relations for Quality Control personnel becomes apparent. They needn't be social scientists -- but they need to know more about human behavior than the layman ordinarily does. The good inspector must be able to criticize a man's work without putting him on the defensive, for example. A few of us can do this without benefit of training; but most of us can do a much better job of it once we understand how man forms his image of himself, how important that image is to him, and the lengths to which he will go to protect it when he feels it is threatened.

7. Let's make the Quality Control function "authoritative" rather than "authoritarian".

We all recognize a potentially explosive situation in the relationship between the hourly rated inspector and the salaried supervisor, simply because of the power which the inspector must have if he's going to be able to do his job. It seems to me there are two parts to the only practical answer to this problem. The first part we've already outlined-- if we select our inspectors carefully and train them properly, the authority they possess on a functional basis will be defined as "that to which we look for an answer", rather than as "that which gives one the power to command". The "command" which they exercise will be fundamentally that of respect -- the same kind of respect that is accorded by the salaried man, whether he is a supervisor or not, to any craftsman who knows his job. This, it seems to me, is the most important kind of "backing" we can give the inspector, whether he be hourly rated or salaried -- the preparation he needs to do his job properly.

The second part of the answer -- and the second kind of backing -- is to be sure that our Quality Control supervisors and their inspectors are "teams" in a truly functional sense. I'm referring now not only to the usual kind of relationships that ought to exist between any supervisor and the people in his work group, but as well to the degree of functional integration and reinforcement the Quality Control supervisor is able to give his inspectors. He must operate not only as an administrator, but as a Quality Control engineer -- does he have the time as well as the training to do what needs to be done in this respect? If the answer is "no", will additional training in administration help him to improve his organization of this phase of his work sufficiently to free him for the needed time out on the floor?

If the answer is still "no", ought we give him some additional help? -- perhaps a

clerk to take the load of paper work off his shoulders, or perhaps a salaried techni-
cian whose only responsibility is the functional performance of the group? Perhaps
even more extensive revision of the administrative structure of Quality Control might
be helpful -- you know the answer to this better than I. What seems important to me is
that the Quality Control supervisor or his representative be not only qualified to pro-
vide his people with authoritative functional back-up, but that he be in a position to
be able to do so.

This is important not only with regard to the quality and uniformity of the job
Inspection does -- it has, as well, a salutary effect on the relationship between the
inspector and the supervisor. When the hourly inspector knows that support is imme-
diately available for him if he needs it -- he is less likely to need it! His whole
approach to the supervisor becomes altered. He is less likely to let emotion color
his presentation if he knows that rescue is at hand when he seems to be getting beyond
his depth; and as a result his effectiveness is increased rather than diminished.

SUMMARY

Actually, we haven't said anything more than this -- the most important thing to
keep in mind about the "human relations challenge of Quality Control" is that we are
exercising the control with regard to people rather than things.

When we keep this in mind, just plain common sense will do the job for us. There's
no mystery involved, once we understand the real nature of our objective.

BAYESIAN DECISION THEORY AND STATISTICAL QUALITY CONTROL [1]

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Bayesian decision theory has had considerable development in recent years and its impact on the field of quality control is being increasingly felt. This type of theory emphasizes the importance of including economic costs and prior knowledge formally in the solution of a problem involving the making of decisions under uncertainty. Since quality control problems virtually always involve decision making with the elements of costs, prior knowledge and uncertainty as essential ingredients, the development is a very logical one. It is an interesting point, however, that although there have been quite a few articles published on the general subject of Bayesian decision theory applied to quality control problems, relatively little of this material has been published in periodicals sponsored by the American Society for Quality Control. [3] As a matter of fact, in an unpublished bibliography by I. R. Savage on articles "in which the economic aspects of the quality control program are emphasized," only five of the ninety-eight items listed appeared in ASQC sponsored publications. Only one of the five articles actually involved Bayesian decision considerations. Perhaps a partial explanation is that a substantial part of the development of Bayesian decision theory applications in quality control has taken place outside this country.

The purposes of this paper are to indicate the basic elements of the Bayesian decision theory approach in a quality control setting and to summarize briefly some of the criticisms this theory makes of traditional estimation and hypothesis testing procedures. A few brief remarks on the historical development of some of the pertinent ideas will be given before proceeding to the critique of classical statistics.

Reverend Thomas Bayes, an English minister who lived in the eighteenth century, developed a theorem which permitted the calculation of the probabilities of "causes" when evidence was available concerning "effects". Specifically, Bayes showed how to calculate posterior probabilities of occurrences of events given prior probabilities of the occurrence of these events. [4] Paradoxes arose in connection with the early

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[3] A notable recent exception to this point is the set of papers by D. R. Cox, A. Hald and G. B. Wetherill which appeared in Technometrics, Vol. 2, No. 3, August 1960.

[4] In Bayes' original work, he assumed equal a priori probabilities. The theorem known today as Bayes' rule which does not require the assumption of equally probable prior events is actually La Place's modification of Bayes' original theorem. The theorem gives the posterior probability of the event A_v, which is one of a partition of events A_i, i=1, 2, ..., n. The appearance of one of the A_i is a necessary condition for the occurrence of another event B. Knowing the conditional probabilities $P(B/A_i)$ and the unconditional probabilities $P(A_i)$, the posterior probability of A_v given that B has occurred is

$$P(A_v/B) = \frac{P(A_v)P(B/A_v)}{\sum_{i=1}^{n} P(A_i)P(B/A_i)} .$$ The theorem answers

the question, Given that event B has occurred, what is the probability that it was preceded by the event A_v? Another way of looking at it is that $P(A_v/B)$ is the revised probability assignment to event A_v after observing evidence B. Bayes' paper "An Essay Towards Solving a Problem in the Doctrine of Chances" was submitted posthumously to the Royal Society in 1763. A reprint of the essay appeared in Biometrika, Vol. 46 (1958).

applications of the theorem because of the use of the "Principle of Insufficient Reason." That is, it was assumed that when the a priori existence probabilities were unknown, they could be taken to be equal. When the prior probabilities are known, whether equal or unequal, there is no difficulty in the application of the theorem. It is probably safe to say, however, that the major obstacle to its widespread application has been the difficulty of determining the a priori probabilities. Modern Bayesian decision theorists, however, hold that legitimate applications of the theorem can be made not only when prior probabilities are known in the objective relative frequency sense but also when they are determined on a "subjective probability" or "personalistic probability" basis reflecting the a priori wagering odds of the investigator concerning the underlying "events" or "states of nature".[5]

There were a number of discussions of Bayes' theorem in connection with statistical quality control early in the history of that field by Molina, Shewhart, Simon and various articles in the Bell System Technical Journal.[6] To give just one example, Leslie E. Simon developed a very interesting set of nomographs [7] based on the Laplacian generalization of Bayes' formula,

$$
W(Q_L, Q_U) = \frac{\displaystyle\int_{Q_L}^{Q_U} W(x)\; \frac{n!}{c!(n-c)!}\; x^c(1-x)^{n-c}dx}{\displaystyle\int_0^1 W(x)\; \frac{n!}{c!(n-c)!}\; x^c(1-x)^{n-c}dx}
$$

where $W(Q_L, Q_U)$ is the a posteriori probability that the proportion of defectives in a lot lies between the limits Q_L and Q_U, $W(x)$ represents the prior probability distribution of lots with proportion defective $Q = x$ and $\frac{n!}{c!(n-c)!} x^c(1-x)^{n-c}$ is the binomial probability that the lot would produce the observed sample of n articles c of which are defective. Simon assumes $W(x)$ is constant, that is, equal likelihood of lot fraction defectives prior to sampling. However, he gives a very interesting discussion of the effects of the prior distribution of lot fraction defective, sample size and sample fraction defective on a posteriori probabilities. The nomographs provide both a posteriori parameter estimates and a priori probability calculations. It seems surprising that wider application has not been made of Simon's early work, not only of the Bayesian concepts, but also of the techniques and ideas developed in his "grand lot schemes". One would only need to add economic costs to Simon's Bayesian mathematical model to have a quite modern formulation.

Turning now to a brief critique of classical statistics, let us consider first of all the case of confidence interval estimation. A typical illustration in a quality control text might run as follows.[8] Take a simple random sample of 10 articles from a large lot. If no defective articles are observed in the sample, the 0.95 confidence limits for the lot fraction defective are 0 to 0.31; if one defective article

[5]See L. J. Savage, The Foundations of Statistics, John Wiley and Sons, 1954 for a discussion of the subjectivistic view of probability.

[6]See L. E. Simon, An Engineer's Manual of Statistical Methods, John Wiley and Sons, p. 166.

[7]Ibid.

[8]See e.g. Acheson J. Duncan, Quality Control and Industrial Statistics, Richard D. Irwin, Inc, Homewood, Illinois, 1959, pp. 427-440.

is observed, the 0.95 confidence interval is 0 to 0.45, etc. It is usually pointed out (correctly) that these are not probability statements concerning the population parameter because the population parameter in the classical approach is not a random variable. As a matter of fact, in classical statistics, probability statements generally concern conditional probabilities of sample outcomes given specified population parameters. The Bayesian point of view would be that these are not the conditional probabilities we are usually interested in. Rather, we would like to have the very thing not permitted by classical methods - conditional probability statements concerning population values given sample information. With the use of appropriate prior distributions, posterior probability statements can, of course, be made about universe parameters considered as random variables. The illogicality of neglecting prior information in making estimates of universe parameters was brought out well, I believe, in a comment of a late colleague of mine to the effect that it had always bothered him that he could make as good a confidence interval estimate in an area he knew nothing about as could a statistician of equal competence who had spent his life working in that area. This suggests the frequently made point that often the classical statistician faced with a decision to make will act in a way that indicates that he does not take completely seriously the inferences dictated by classical methods.

An illustration of a situation in which one would not be willing to act on a confidence interval estimate neglecting prior information follows.[9] Suppose that a large lot of articles had been produced and by means of 100 percent inspection it was determined that 80 percent of the articles were "good" according to specified standards. Some of the defectives were subsequently reworked and rectified, but through poor management and bad record keeping the identity of the good and defective articles was lost. The lot was then placed intact in a suitable storage area for a very brief period during which no deterioration took place. Prior to shipment to the customer, management decided to take a sample of articles from the lot and to set up a confidence interval estimate for the percentage of good articles. A sample was drawn and although the rules of random sampling were followed, there were a sufficient number of defective articles concentrated in this particular sample to yield a 0.95 confidence interval estimate of 65 percent to 75 percent good articles.[10] Since it is known that at least 80 percent of the articles in the lot were good, (as a matter of fact there is a reasonable presumption that the percentage is substantially higher than 80 percent), the confidence interval estimate cannot be taken seriously for a conclusion about the quality of this lot. However, the point of this illustration is that classical statistics permits the inference to be drawn only from the confidence interval statement and confidence coefficient (or decision rule) must be selected before examining the sample evidence. In the Bayesian approach, a prior distribution of percentage of good articles which had a lower limit of 80 percent would have forestalled an inference such as the one given above since the posterior distribution would then have had a corresponding lower limit of 80 percent.

Turning now to a second illustration, the essential ingredients of the Bayesian approach will be indicated by means of a simple hypothesis testing example in an acceptance sampling setting.[11] This example will also illustrate some of the elements of the critique of traditional hypothesis testing. In particular, it will demonstrate that if tests of hypotheses are conducted in the usual manner of setting decision rules of rejecting or failing to reject hypotheses at pre-set levels of significance, non-optimal decisions may be made.

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[9] This example is similar to one given by Schlaifer, R., in Probability and Statistics for Business Decisions, McGraw-Hill Book Co., Inc., N. Y. 1959, pp. 665-666.

[10] The following quotation at the head of Chapter 6 in Leslie E. Simon's, An Engineer's Manual of Statistical Methods covers the situation of the sample in which fate has been unkind to the sampler:

"Alle Kunst is umsumst
Wenn ein Engel auf das Zündloch brunzt."
- An Old Folk Saying

[11] The idea for this example was derived from a similar illustration involving drilling alternatives in the oil industry in an unpublished note written by Professor Howard Raiffa.

Assume a situation where a manufacturing company does inspection on a lot by lot
basis for a particular product prior to the movement of these lots between two depart-
ments of the company. Acceptance sampling inspection is carried out by selecting a
single random sample of n articles from each lot. Further assume that there are only
three different types of lots produced, namely 2 percent, 5 percent and 7 percent de-
fective. The manufacturer wants to accept and send to the next stage of production
lots that are 2 percent defective but he wants to reject and rework lots that are 5
percent or 7 percent defective. In decision theory terms, therefore, there are three
"states of nature" or possible "events" - 2 percent, 5 percent and 7 percent defective
lots, and two terminal acts - "accept" and "reject". A payoff matrix is given in
Table I, showing the costs incurred under the various combinations of events and ac-
tions. If a "bad" lot is accepted, the losses due to repairs which become necessary
at later stages of production are respectively $300 if the lot is 5 percent defective
and $500 if the lot is 7 percent defective. If a "good" lot, that is, a 2 percent de-
fective lot, is rejected, the losses attributable to seeking out defective product
and the making of unnecessary repairs has been established to be $200. All other
costs are shown as $0. It will be noted that the relevant costs in this type of prob-
lem are "opportunity losses", that is, the additional losses incurred by not making the
correct decisions with respect to lots submitted for inspection.

TABLE I

PAYOFF MATRIX SHOWING OPPORTUNITY LOSSES FOR ACTIONS OF
ACCEPTING AND REJECTING LOTS WITH
SPECIFIED PERCENTAGES OF DEFECTIVE ARTICLES

Event (Lot Percent Defective)	Act	
	Reject	Accept
2	$200	$ 0
5	$ 0	$300
7	$ 0	$500
Expected Losses	$100	$200

On the basis of past production performance it has been determined that 50 per-
cent of the lots produced are 2 percent defective, 25 percent are 5 percent defective
and 25 percent are 7 percent defective. These past relative frequencies, in the ab-
sence of any further information, are adopted as the prior probabilities that 2 per-
cent, 5 percent and 7 percent defective lots will be produced and submitted to the
given sampling plan for acceptance or rejection. (Table II).

TABLE II

PRIOR PROBABILITIES (RELATIVE FREQUENCY OF OCCURRENCE)
OF LOTS WITH SPECIFIED PERCENTAGE DEFECTIVE ARTICLES

Event (Lot Percent Defective)	Prior Probabilities
2	.50
5	.25
7	.25
	1.00

Formally, the assumption is that the prior distribution of the probability p of a de-
fective item is the mixed binomial distribution

$$(a_i, p_i), \ (i = 1, 2, 3) \text{ where } \sum_{i=1}^{3} a_i = 1$$

Expected losses for the two actions of acceptance or rejection are shown in Table I.
These are mathematical expectations of loss under each action if no sampling is done

and are obtained by summing the products of the prior probabilities and losses under
each action. Although expected monetary values are used throughout the illustration
given here, it may be noted that in situations where they are not appropriate guides
to decision making, the analysis should be carried out in terms of expected utility
values.

A "game tree" is given in Figure 1 which serves to indicate the various actions
that may be taken and their economic consequences. Our first choice is either to sam-
ple and inspect n items from the submitted lot or not to sample nor inspect.[12] Sup-
pose we choose not to sample the lot. Starting at node (a) at the left, therefore,
and following the "do not inspect" branch of the tree, we move along to node (b) where
we face the choice of either accepting or rejecting the lot. If we make the choice of
rejecting the lot, we move to node (c). There are now three possibilities; the lot is
either 2 percent, 5 percent or 7 percent defective. Weighting the economic consequen-
ces of these three possible outcomes by their prior probabilities, 0.50, 0.25 and 0.25,
we obtain a loss of $100 as the expected monetary value of this decision. This is in-
dicated at node (c). A similar calculation for the decision to accept the lot yields
a loss of $200, shown at node (d). Now the choice is between rejection or acceptance.
The optimal decision is obviously to reject the lot incurring the smaller loss. The
branch marked "accept" is blocked off, therefore, as indicated by the two wavy lines.
Moving back to vertex (b), $100 is shown there, indicating the loss that would be in-
curred if we take the optimal act under the choice "do not inspect."

On the other hand, suppose, at the outset, (at node (a)), our decision is to sam-
ple and inspect n items. Making this choice, we move down to branch point (e). The
results of the sampling inspection then determine which branch we follow. The pos-
sible results of sampling have been classified into three categories. The number of
defectives, r, may have been equal to or less than some number d_1 $(d_1 \leq n)$. It may
have been greater than d_1 but equal to or less than d_2, $(d_1 < d_2 < n)$. Finally, the
number of defectives may have been greater than d_2. These three types of results, for
purposes of brevity, are referred to as Type X, Type Y and Type Z information. In
Table III, a joint frequency distribution is given for sample results and "states of
nature" or "events". It may be assumed that these frequencies were derived from a
large number of past observations, and therefore may be taken to represent probabil-
ities in the relative frequency sense. For example, in the past, in .42 of the lots
inspected, the number of defectives observed was d_1 or less and the lots were 2% de-
fective. In terms of marginal frequencies, in .60 of the lots inspected Type X infor-
mation was observed $(r \leq d_1)$, in .20 of the lots Type Y $(d_1 < r \leq d_2)$ was observed,
and in .20 of the cases Type Z $(r > d_2)$ was observed.

Returning now to the game tree, we observe the three branches representing X, Y,
and Z types of information emanating from node (e), marked with their respective prob-
abilities .60, .20, and .20. Suppose Type X information $(r \leq d_1)$ were observed. Mov-
ing ahead to branch point (f), we can either accept or reject the lot. If we reject,
we move to node (g); if we accept, to node (h). At these points, the probability
questions that must be answered are of the Bayes'rule or a posteriori variety. For
example, the probabilities shown on the three branches stemming from (g), .70, .20,
and .10 are the posterior probabilities, given Type X information, that the lots con-
tain 2 percent, 5 percent and 7 percent defectives, respectively. Thus, they repre-
sent revised probabilities of the occurrence of these three events, after having ob-
served a particular type of sample evidence. In Table IV are shown the calculation of
these posterior probabilities by the use of Bayes' theorem. Table V shows these
posterior probabilities for all three types of sample information. It may be noted
that these probabilities may have been derived from Table III by dividing joint prob-
abilities by the appropriate marginal probabilities, e.g. $.70 = \frac{.42}{.60}$.

Now looking forward from node (g) and using the posterior probabilities .70, .20 and
.10 as weights applied to the losses attached to the three events 2, 5 and 7 percent
defective lots we obtain an expected payoff of a loss of $140. This figure is entered
at node (g). Comparing it with the corresponding figure of $110 for "accept", we
block off the action "reject" as being non-optimal. Therefore $110 is carried down
to node (f), representing the payoff for the optimal act upon observing Type X $(r \leq d_1)$
information. Similar calculations yield $60 and $20 at (i) and (l) for Types Y and
Z information. Weighting these three payoffs by the prior probabilities of obtaining

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(12) There are, of course, other possible choices which are not considered in this il-
lustration such as other types of sampling plans and 100 percent inspection.

X, Y and Z information, we obtain a loss of $82 as the expected payoff of sampling and inspecting n items. Note that it is assumed that optimal acts will be taken after the observation of the sample evidence. Comparing the $82 with the $100 obtained under the act "do not inspect", we see that it would be worthwhile to pay up to $18 for the cost of sampling and inspection. This difference represented by the $18 is usually referred to as the "expected value of sample information". Since the cost of sampling and inspection is given as $5, it pays to sample and inspect n articles, i.e., to purchase experimental evidence, rather than to act without obtaining this evidence.

The point may be made here that decision theory analysis provides much more rational answers to the questions, "should we sample? If so, how much should we be willing to pay for sample information?", than does the traditional statistical approach. It is in this area that decision theory makes a particularly valuable contribution - more so even than in answering the question as to which terminal act to take, once all the experimental evidence is in.
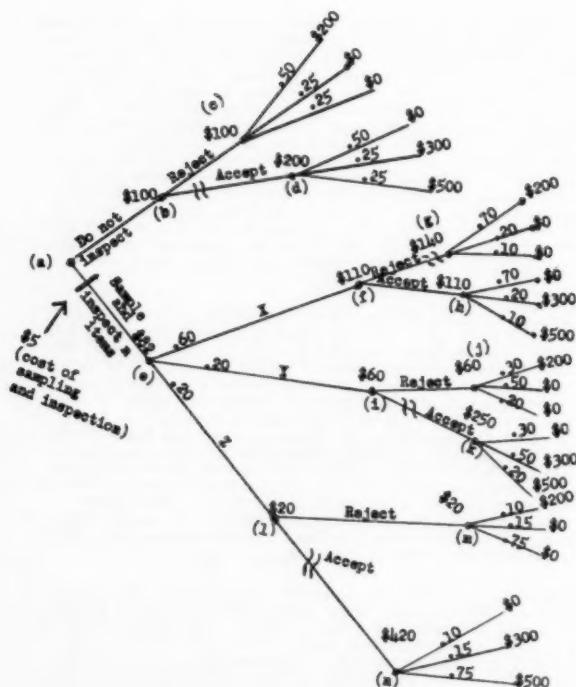
FIGURE 1

GAME TREE FOR ILLUSTRATIVE PROBLEM

TABLE III

JOINT FREQUENCY DISTRIBUTION OF SAMPLE
RESULTS AND EVENTS

Event $\left(\begin{array}{c}\text{Lot Percent}\\\text{Defective}\end{array}\right)$	Sample Results			
	Type X $r \leq d_1$	Type Y $d_1 < r \leq d_2$	Type Z $r > d_2$	Total
2	.42	.06	.02	.50
5	.12	.10	.03	.25
7	.06	.04	.15	.25
Total	.60	.20	.20	1.00

TABLE IV

CALCULATION OF POSTERIOR PROBABILITIES OF EVENTS
GIVEN TYPE X INFORMATION $(r \leq d_1)$

Event $\left(\begin{array}{c}\text{Lot Percent}\\\text{Defective}\end{array}\right)$	$P(A_i)$	$P(X/A_i)$	$P(A_i)P(X/A_i)$	$P(A_i/X)$
2	.50	.84	.42	.70
5	.25	.48	.12	.20
7	.25	.24	.06	.10
			.60	1.00

TABLE V

POSTERIOR PROBABILITIES OF EVENTS AFTER SAMPLE EVIDENCE
OF TYPES X, Y AND Z HAS BEEN OBSERVED

Event $\left(\begin{array}{c}\text{Lot Percent}\\\text{Defective}\end{array}\right)$	Sample Results		
	Type X $r \leq d_1$	Type Y $d_1 < r \leq d_2$	Type Z $r > d_2$
2	.70	.30	.10
5	.20	.50	.15
7	.10	.20	.75
	1.00	1.00	1.00

All possible decision rules or "strategies" will now be considered and utilized as a means of commenting on traditional hypothesis testing procedures. There are ten possible strategies that may have been considered in the illustration given above. These are enumerated in Table VI. An "R" denotes reject; an "A" denotes accept. Therefore, for example, decision rule or strategy number (1) means do not sample and always reject; decision rule (4) means sample and accept regardless of the type of sample information observed; decision rule (5) means sample and accept if Types X or Y information are observed, i.e. if d_2 or fewer defectives are observed; decision rule (6) signifies acceptance if d_1 or fewer defectives are observed. A choice between decision rules (5) and (6), therefore, would mean, in acceptance sampling terms, a choice between a single sampling plan with an acceptance number of d_2 and one with an acceptance number of d_1.

TABLE VI

POSSIBLE DECISION RULES BASED ON INFORMATION
DERIVED FROM SINGLE SAMPLES OF SIZE n

Sample Information	No Sampling			S a m p l i n g						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Type X ($r \leq d_1$)	R	A	R	A	A	A	A	R	R	R
Type Y ($d_1 < r \leq d_2$)	R	A	R	A	A	R	R	A	R	A
Type Z ($r > d_2$)	R	A	R	A	R	R	A	A	A	R

Operating characteristic curves may now be prepared for each of the decision rules. The only ones that are shown, however, are for strategies (5), (6) and an ideal OC curve, (Figure 2). It can easily be shown that all other decision rules are "dominated" by (5) and (6); i.e. (5) and (6) are closer to the ideal curve for all fractions defective in incoming lots. Rules other than (5) and (6) under sampling do not, in fact, make much sense. For example, in rule (8), lots would be rejected if the number of defectives in a sample of n articles were d_1 or less, but accepted otherwise. Although the points on the operating curve are joined by straight lines, probabilities should be read, of course, only for the discrete points 2 percent, 5 percent and 7 percent defective.
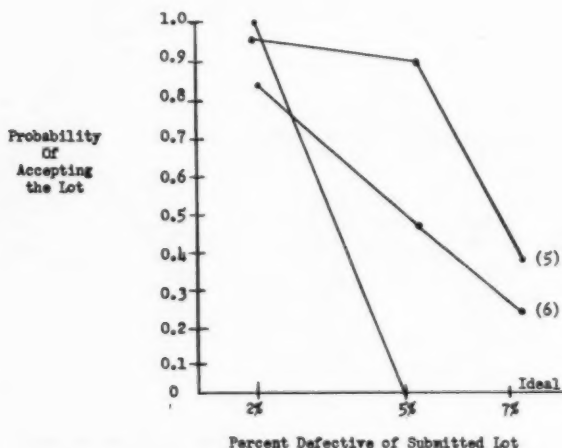
FIGURE 2

OC CURVES FOR STRATEGIES (5) AND (6)
AND THE IDEAL OC CURVE

By means of the earlier analysis, decision rule (6) was shown to be optimal. That is, the conclusion on the basis of the game tree analysis was that the minimum opportunity loss would be obtained by accepting the lot if Type X ($r \leq d_1$) information were observed and rejecting the lot if Type Y or Type Z information were observed ($r > d_1$).

Now, suppose this problem had been approached from the standpoint of a "null hypothesis" testing procedure. The hypothesis H_0: $p = 2$ percent would be tested at some preselected level of significance. Assume it had been decided that the maximum probability of a Type I error should be 5 percent. That is, it is decided that submitted lots that are 2 percent defective should be rejected no more than 5 percent of the time. It will be noted from Figure 2 that rule (5) meets this criterion but rule (6) does not. Therefore, traditional hypothesis testing procedures would require the use of strategy (5), which has been shown to be non-optimal. Referring back to Figure 1, it can be seen that an expected loss of $114 would be incurred under strategy (5), [(.60 × $110) + (.20 × $220) + (.20 × $20)], as compared to an expected loss of only $82 under strategy (6).

To summarize, Bayesian decision theory criticizes traditional statistical hypothesis testing procedures on various grounds: (1) these hypothesis testing procedures do not provide a method for combining prior information with experimental evidence and (2) too much burden is placed on significance levels as a means of deciding between alternative acts – specifically, no formal method is provided for the inclusion of economic costs as a part of the decision making process. In conclusion, it should be pointed out that Bayesian decision procedures are extremely flexible. For illustrative purposes, a single sampling scheme was investigated in this paper. As a generalization, all possible sample sizes and acceptance number combinations could conceivably be tested to seek out optimal combinations. Furthermore, sensitivity analyses could be conducted to determine the effects of variations in prior probabilities and changes of costs in the payoff matrix. Finally, the procedures generalize to the consideration of more complicated sampling plans such as double sampling and sequential analysis.

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WORK SAMPLING

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The purpose of this paper is to discuss the technique of Work Sampling, and to suggest ways in which the practicioner in the field of Statistical Quality Control may be of help to himself and his management with respect to the use of Work Sampling. Because Work Sampling was originated by an eminent statistician, L.H.C. Tippett, and because this audience is quite sophisticated in its acceptance of the concept of gathering information by means of sampling, no extended discussion of the technique is appropriate. However, I should like to offer a definition of the technique:

(1) "Work Sampling is a measurement technique for the quantitative analysis, in terms of time, of the activity of men, machines, or of any observable state or condition of operation. Work Sampling is particularly useful in the analysis of non-repetitive or irregularly occurring activity, where no complete methods and frequency distribution is available . . . . .

A Work Sampling study consists of a large number of observations taken at random intervals; in taking the observations, the state or condition of the object of study is noted, and this state is classified into predefined categories of activity pertenent to the particular work situation. From the proportions of observations in each category, inferences are drawn concerning the total work activity under study . . . . .

The underlying theory of Work Sampling is that the percentage of observations recording a man or machine as idle, working, or in any other condition reflects to a known degree of accuracy the average percentage of time actually spent in that state or condition. If observations are randomly distributed over a sufficiently long period of time, this theory is held to be true, regardless of the nature of the observed activity."

The important thing to remember in using Work Sampling is that it is merely one of several work measurement techniques. As in any measurement situation, the first thing to be done is to match the measuring tool to the demands of the job. The particular characteristic of directed human effort, or work, that is most descriptive of its nature is the extent to which particular motion patterns repeat themselves, or in other words whether the job represents "mass production" or "job shop" activity. Too many people equate work measurement with the stop watch, and thus ignore significant advances in the field which have taken place in the past few years. Everyone here has heard factory management say "Quality Control won't work here, our lots are too small." These same people say "Work Measurement does not apply in our area, our work is too irregular." And in both cases the real answer is that techniques designed for measuring large numbers of uniform events cannot be expected to work in situations where we do not <u>have</u> large numbers of uniform events.

Thus, the first thing we must do is to develop a scale of precision of measurement which can be matched with the degree to which the work being measured is repetitive. All the work measurement techniques to be described are in use at present, but of course it must be recognized that to ask "Which is best?" is foolish. The question should be: "Which is best for the situation at hand?" For highly repetitive work, which does not involve a process-controlled element, the predetermined human work time is appropriate. In this technique, "basic" movements of the hands and body members are assigned times for their accomplishment. These times are in the order of fractions of a second, and a motion pattern is described in terms of specific movements with corresponding times. MTM, Work-Factor, BMT and other proprietary systems are typical of such predetermined work times. They are very useful, but expensive and time-consuming. One company estimates that it takes six hours' time to build up data on one minutes' worth of work. However, for repetitive work this technique is most effective.

Stop watch time study is widely used on work that is repetitive, but in which process variations may occur. This technique has its faults, but is still widely used. Its reliability compares closely with predetermined work times, on the order of minus or plus ten percent at the two sigma level of confidence. But the work must be repetitive, and skill is required in application. Essentially a sampling technique, stop

watch time study is susceptible of control-chart analysis, and variability of readings frequently is analyzed using standard Quality Control Chart factors.

From both predetermined human work times and time study we develop tables of standard data for use in rate setting. These tables relate some physical characteristic of the product to the amount of time required to perform a given operation on the product. In passing, this sounds familiar to the Quality Control man because this is almost exactly what he does in his work. It might be added that this is an area in which he can contribute to work measurement to a much greater extent than he now does.

Moving now to work that is non-repetitive in nature, such as clerical, maintenance, material handling and research and development, we find that such activity has been largely left unmeasured. This is true because prior to the use of Work Sampling, no measurement technique seemed appropriate, and also because until the past few years this work was not recognized as being capable of measurement and control. Better management practice, and the growing impact of automatic devices have changed this. Now the emphasis is on equipment and personnel utilization, rather than on the "work content" of the job. Further, many labor groups, faced with technological unemployment, have resisted management's efforts toward cost reduction through layoff. The airline engineer's strike, the harbor pilot's strike and the last steel strike all had as the central issue the question of manning or work rules. It has therefore become more important to establish labor standards in non-repetitive work. For this Work Sampling has proved to be a most effective technique. Because Work Sampling is convenient and economical, it is quite reasonable to suggest that a study be taken to extend over a period of a month, or better still, five weeks. In this way, if there is a monthly cycle it can be defined; also, the advantages of a larger sample, spread over a longer period of time, need not be stressed to this group.

But Work Sampling in and of itself provides only information about the _input_ to the job, in terms of time utilization of the people involved. This must be matched with an _output_ in terms of fairly well-defined work units. In maintenance, for example, units of output might take the form of job orders, routine preventive inspections and hours of unscheduled down time. In this latter unit, of course, a low figure is usually considered desireable. It is in this area of defining and measuring units of output that the Quality Control man can be of great assistance to the effort. This is true because he is accustomed to dealing in distributions, and the causes and definition of variability. In some cases, an old hand in time study will carry over from his "savvy" in measuring repetitive work the concept that unless every single work unit is very precisely described (and equally precisely measured), no true measurement exists. Unfortunately, in dealing with non-repetitive work, this simply is not true by the definition of "non-repetitive work." The secret of ultimate control of this type of labor cost is to close in on the exact figures by degrees, starting with an imprecise measurement, and exercising judgment as to the point at which it becomes uneconomical to pursue precision. The Quality Control man is accustomed to doing this, because control limits are after only a set of decision rules, predetermined when the sampling plan is designed. The time study man often is used to working only with averages, and imparts to many of these a sort of sacred quality in contradiction of the facts.

This is not to say that a competent, well trained Industrial Engineer harbors these notions. But unfortunately there are many in work measurement who think that "X-bar is the name of Hopalong Cassidey's ranch", and you may encounter some of these. There are a large number of well-trained Industrial Engineers, and I invite your attention to the "JOURNAL OF INDUSTRIAL ENGINEERING", which is a first-class publication of the American Institute of Industrial Engineers. This is a professional society in the best sense of the word. Among members of this society there is a broad understanding of statistical theory. But there are many practicing in the field of work measurement who are not knowledgeable in statistics. Further, Work Sampling, a simple and direct measurement, is quite often used by managers and others who claim no competence in work measurement. These people in particular are in need of your aid.

Basically, the problem in selection of work units is the same one that Quality Control engineers face every day. The units must be defined, an accurate count must be made of volumes or numbers, and above all the units must be meaningful in their relationship to the categories of the work sampling study. To take these one at a time, anyone here will recognize the problem of definition. Work units must be classified, a control point set up to obtain consistent sorting by classes, and a mechanism set up by which the integrity of the classification is maintained. For example, one maintenance department increased its volume of work under a control program by simply starting to record as "job orders" certain small repair jobs that previously had not been recorded, but were picked up by the mechanics in their spare time. In terms of work measurement, work

unit counts are an essential, because we must identify hours with output, and looking ahead to eventual control and perhaps incentive payment, the system should be consistent with management's desire to obtain control. Notice that the word is "obtain." This is used because most applications of Work Sampling to work standards come where no control exists at the start of the study. Finally, the problem of relating the work unit to the categories of activity is important in the same sense that relating a physical characteristic of product to the performance of that product is important in Quality Control. All we have from a Work Sampling study is a series of category proportions, and we must then relate these to work units to produce a standard of "time per unit".

Great emphasis has been placed on the work unit because it is in this area that many Work Sampling studies are lacking. Also it is in this area that greatest progress can be made toward the eventual reduction of cost. Generally speaking, we do not expect craftsmen or clerical workers to work harder when they are working under a system of labor control. The most realistic objective is to have them devote more of their time to productive activity, and less to non-productive activity. One basic concept in which much progress can be made is the idea that maintenance, clerical and other "indirect" employees really perform a service, the quality and quantity of which can vary. This is consonant with the thinking of the individual who appreciates the concept of the distribution, but unfortunately it is not widely appreciated among managers of some activities. Make a test yourself. Ask your maintenance supervisor what his output was for a previous month. The chances are good that he will reply "X thousand dollars", or perhaps he will say "I had seventy mechanics on the payroll." The first step in getting a better answer, of course, is to define the output. Simply by taking a listing of jobs, and forcing yourself to write opposite each the output of these jobs in terms of work units of known quality you will take a giant step toward control of labor cost. This is true because one way to reduce cost is to eliminate work, and many work units will not stand close scrutiny when the criterion is the necessity of the task in the face of planned cost reduction. But unless you ask the hard question of necessity cost reductions will not come on a rational basis.

Once work units have been established and the Work Sampling results matched against these, another job must be done in which you can be of real assistance. That is in establishing the standards themselves through correlation and regression techniques. The end result of a study should be a series of graphs or formulae by which a known output can be related to a standard input of man hours necessary for its accomplishment. If competent industrial engineers are working on the problem, your advice will be sought. If no such men are available, you may be called on to establish these relationships. A word of caution is in order here. Be sure to question the degree of accuracy which is desired. If the program is one designed to obtain the first step in control, an error of the order of perhaps fifteen percent may be normal. As more experience is gained, slightly more accurate results may be obtainable.

One basic question on which you may be asked to give advice is the sample size in Work Sampling. Since Work Sampling studies have so many applications, a wide variety of answers may be given. The most common fault seems to be to insist upon a high degree of reliability for all studies, and the application of rigid rules to obtain this. As in Statistical Quality Control, all sampling plans do not have the same objective, and such blanket rules can be silly. The rule of reason should prevail, and the basic parameters of the difficulty in obtaining observations, the size of the group being observed, and the other demands made upon the observers' time should be considered. Articles have been written seriously suggestion sample sizes of over three million observations. But since the most common use of Work Sampling is in fact-finding and in the establishment of standards for non-repetitive work, it is obvious that samples of a thousand or so observations on particular groups of employees seem more logical.

One final thought should be advanced. The very acceptance by some managements of the concepts that sampling is in itself a useful tool of management is of importance to this audience. The further questions raised by the definition of work units and their correlation with the results of Work Sampling provide those with a skill in statistical inference with a golden opportunity to extend their service to management. It is suggested that this opportunity should be seized. With the trend toward more mechanized operation, greater emphasis of equipment utilization, and the growing importance of service-type non-repetitive work, the technique of Work Sampling is bound to become more widely used. You in this audience can be of real assistance to your employers in providing some of the necessary statistical advice. You will also find that it is an interesting technique, and one that will provide an opportunity in its application for your own professional growth.

MANAGEMENT'S CHALLENGE FOR PRODUCT RELIABILITY

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For many years the customer has accepted products that initially can be inspected and tested, and considered satisfactory at a "time zero" condition which upon occasion in field use have proven to have deficiencies preventing optimum customer useage. Examples of estremely high maintainability costs because of product failure to meet operational useage requirements have been cited again and again in the reports of James Bridges of OASD (R & E) - Commercial industry could offer an endless list of warranty, customer goodwill adjustments and other cost balancing options to "sooth" customer irritation.

With recent years, an appreciable growth has occurred in contractual requirements for pre-test under field use enviornments that concern the time domain: e.g. "shall run 100 hours of use with 90% confidence" ... "at least 85 out of each 100 shall fire when required"..."Shelf life deterioration will not be greater than 5% over a two year period"..."Minimum life shall be 50 hours within 95% confidence level".

With the impact of military specifications containing difinitive reliability clauses such as AGREE procedures and in the commercial field, with automobile manu- facturers offering 12 months warranty where previously three month warranty had pre- vailed, it is clear the trend for assurance of product performance is becoming a factual customer requirement.

How does management prepare to meet this customer requirement?... What philosophy change must take place and how does one organize to insure control through the Engineering Design and on to the manufactured product.

This presentation approaches the problem from the Top executive view of estab- lishing controls and balance to assure product reliability. The appraisal deals with delegated authority, responsibilities, audits and costs.

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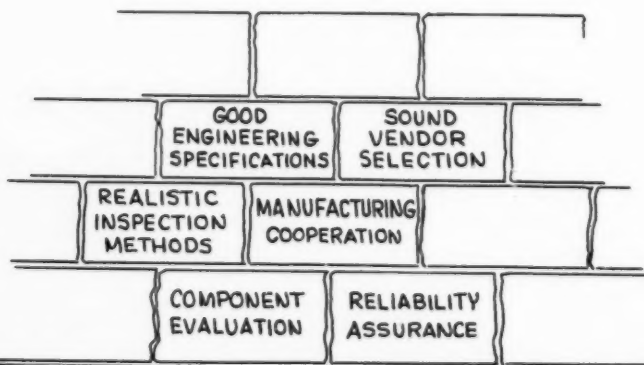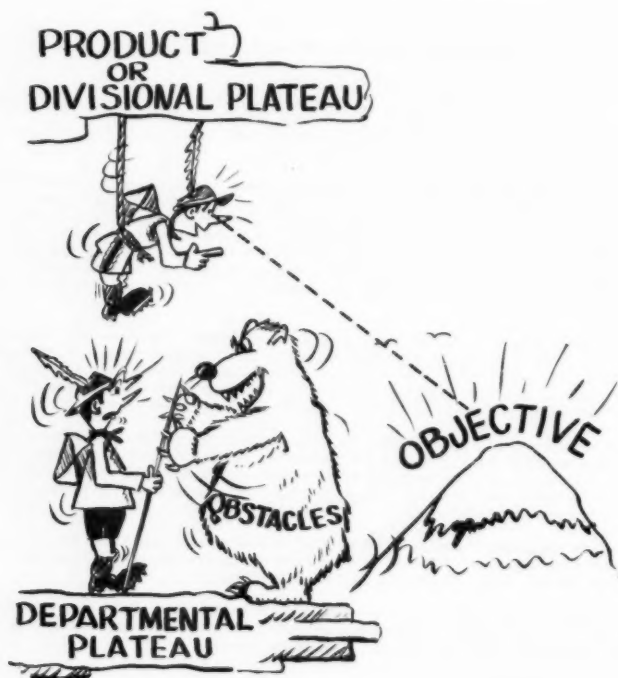
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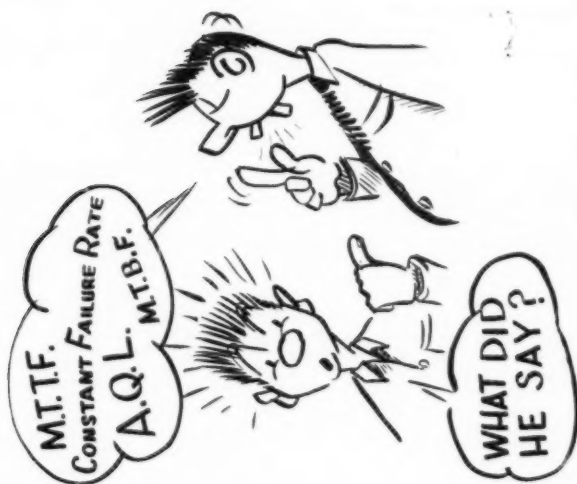
CLARIFICATION OF MEASUREMENT   TECHNICAL GOBBLYGOOK

HOW RCA MEETS AGREE TEST REQUIREMENTS

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INTRODUCTION

RCA has been and is presently producing several electronic systems which must meet the reliability test requirements of the Task Group 3 section of the Advisory Group on the Reliability of Electronic Equipment document (AGREE). The Task Group 3 section of AGREE has been adopted by the Air Force and is being included in revised form in most equipment contracts now being awarded. This paper will discuss the implementation and follow-up that was needed to meet the AGREE requirements. A comprehensive review of the results encountered during AGREE testing will also be provided.

The Air Force adaptation of AGREE requires continuous reliability testing of hardware throughout the life of a contract to assure that equipments meet contractual mean-time-between failure (MTBF) requirements, and periodic longevity tests to assure that equipments meet the contractual service life requirements. To provide this assurance the contractor must place the first twenty-two equipments produced on a contract into a reliability test, each to be tested a specified minimum number of hours. This reliability test is conducted under a combination of environmental conditions which simulate the environment the equipments will face in service (figure 1). As the equipments are tested, operating time and failures are accumulated and matched against a sequential sampling plan having time and failures as the two variables (figure 2). The contractual mean-time between failure requirement, plus the desired confidence of measurement as a tolerance around the MTBF, is the basis for the derivation of the sequential plans' accept or reject criteria. The reliability test continues until either an accept or reject decision is reached. When an accept decision is reached, the initial month's shipments can be made. Each month thereafter, a specified sample of equipments is placed on reliability test and operated until a decision is reached. Shipments of equipments not subjected to the reliability test can be made only if an accept decision has been obtained. A reject decision halts shipments until corrective action is taken, and the contractor can verify the effectiveness of his corrective action by successfully reliability testing either 37 or 50 consecutive equipments against the criteria of the sequential sampling plan.

It should be apparent from this discussion of the AGREE reliability test that failure to pass the initial and monthly reliability tests can cause the contractor severe hardships. Schedules will be missed, billings will be lost, and costly rework and retest will result before shipments can again be resumed. The contractor, therefore, should take positive steps prior to the reliability test to assure himself that the finished product will meet the AGREE requirements.

PRELIMINARY PLANNING

RCA received its first production equipment contract requiring AGREE in February, 1959, for Airborne Time Division Data Link systems. Although RCA had prided itself on producing equipments of high reliability, this was the first time that RCA would be contractually required to demonstrate monthly compliance with a contractual MTBF under "AGREE" rules.

As thought was given to meeting the AGREE requirements, it became apparent that RCA's tight process control system would have to be further re-inforced. This process control system would have a three-fold objective; first: to push the debugging phase as far back in the assembly and test cycle as possible; second: to reduce the influences of the human factor; and third: to assure the customer and RCA that each system, whether it was subjected to the AGREE test or not. would meet the contractual MTBF.

Table I compares the normal RCA Control of two years ago, and the controls now being used on all AGREE programs. An asterisk indicates that a new control has been established.
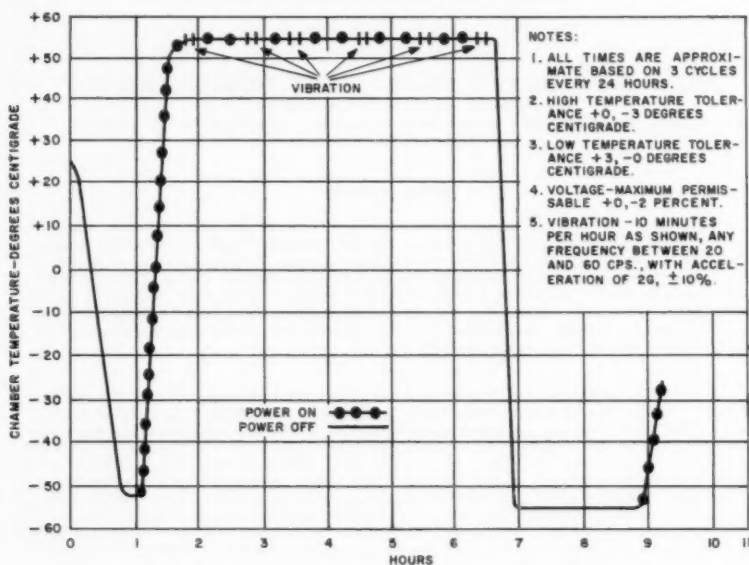
Figure 1. AN/ARR-60 and AN/ARR-61 Specified Environmental Cycle for Reliability Testing
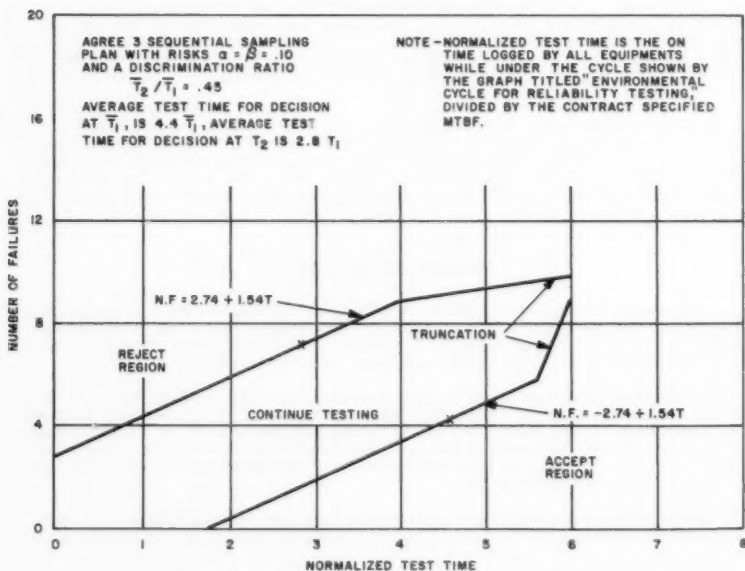
Figure 2. AN/ARR-60 and AN/ARR-61 Accept-Reject Criteria

Table I — Comparison of Process Controls

NORMAL PROGRAM	AGREE PROGRAM
1. Contractual Review	1. Contractual Review
2. Design Review	2. Design Review
3. Reliability Predictions	3. Reliability Predictions
4. Quality Control Acceptance of Engineering Models	4. Quality Control Acceptance of Engineering Models
5. Award of Purchase Orders.	5. * Pre-purchase Order Award Surveys * Vendor Ratings. Award of Purchase Orders
6. Supplier Quality Field Coverage	6. Supplier Quality Field Coverage * Suppliers Burn-in Black Boxes * Purchase Specification Requires MTBF Demonstration
7. Purchased Material Inspection	7. Purchased Material Inspection
8. Printed Circuit Assembly and Test.	8. Printed Circuit Assembly and Test * Printed Circuit Burn-In * Printed Circuit Environmental Tests
9. Assembly and Wiring.	9. * Visual Acuity, Color Discrimination, and Manual Dexterity tests for operators * New wiring, soldering techniques * Controlled atmosphere for Assembly and Test * Increased Programmed Automatic Circuit Checkers
10. Black Box Bench Tests.	10. Black Box Bench Tests * Black Box Burn-in Tests employing variable combinations of environments, such as Temperature and Vibration
11. System Test	11. System Test
12. System Burn-In	12. System Reliability Tests (AGREE)
13. Final Acceptance	13. Final Acceptance
14. Packing and Shipping	14. Packing and Shipping
15. Lab. Analysis of Repetitive Failures	15. * Lab. Analysis of ALL Failures
16. - - - - - - - - - - - - - - - - -	16. * Return of Failed Parts to Suppliers for Corrective Action
17. Data Reporting	17. Data Reporting * Special AGREE Forms and Tags. * Engineering Failure Analysis.
18. Training Programs and Instruction. Testers and Test Supervision. Inspectors Assembly Operators.	18. Training Programs and Instruction. Testers and Test Supervision. Inspectors * Management

PROCESS CONTROL

Quality Control in Engineering

Quality Control had been involved in the processing, inspection and acceptance of Engineering-built models for several years prior to AGREE. It was realized, however, that

many initial production problems could be eliminated if Quality and Process personnel were assigned to Engineering through the design and prototype stages. Quality Control Technicians and Process personnel were made responsible for determining the compatibility of mechanical designs with military specifications and assembly techniques, development of assembly and test procedures, and inspection of assemblies to detect and correct MIL-SPEC and good quality practice violations, in order to make the transition from engineering development to factory production as smooth as possible. As a result of this integrated program, the number of Change Notices was reduced materially.

The success of these activities has led to establishing an Engineering Quality Control section which has the responsibility of servicing all military engineering contracts, regardless of whether or not AGREE is involved.

Burn-in

As an outgrowth of many meetings and discussions prior to the start of production, it was concluded that one of the two most important steps that manufacturing could take to assure equipment passing the AGREE test would be to debug the systems as far back in the production cycle as possible. Accordingly, exhaustive environmentally stressed debugging tests were established at selected components, printed circuit, selected sub-assemblies, and black box levels, as opposed to debugging tests under ambient bench test conditions on black boxes and systems.

All suppliers who build major assemblies are required to burn-in their units for given periods of time under the same environmental conditions imposed on RCA built units. All printed boards are subjected to a dynamic bench test at room temperature; at the temperature extremes of the specifications; and at room temperature again. Under these conditions, each board receives about 5 hours of testing. Each black box is tested for 48 hours under the same environment as the system encounters in the AGREE test. This debugging procedure results in all black boxes, sub-assemblies, and components undergoing the same environmental stress whether they are sampled in AGREE or not. (The results of the complete debugging cycle are shown in figure 3.)

Assembly

Tightly controlling assembly processes and methods was considered by management to be just as important a technique in producing reliability as pushing the debugging phase back into
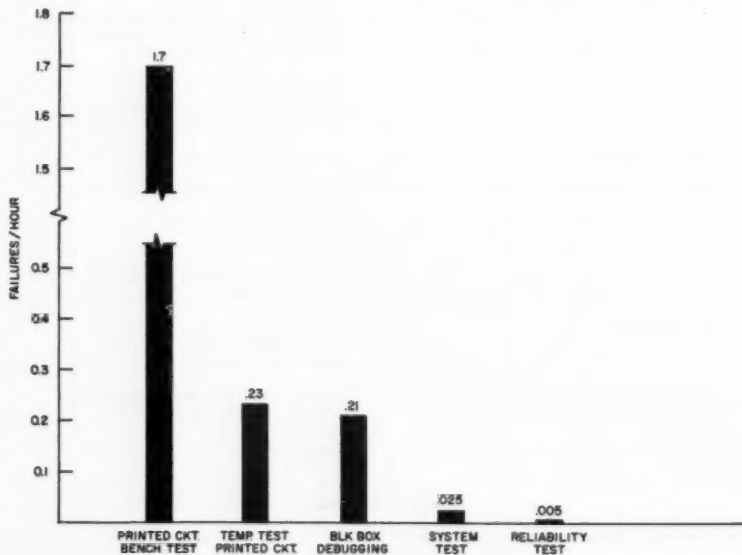
Figure 3. ARR-60 Data Link De-bugging Cycle

the manufacturing cycle. In addition to normal controls, such as variable and attribute control charts, failure reporting, and laboratory analysis of repetitive failures, special tests for assembly operators, a controlled assembly environment, new soldering methods, laboratory analysis of all failures, special failure reporting forms, and a closed information loop involving Factory and Engineering Quality Control were introduced.

All assembly operators are required to pass a visual acuity, color discrimination, and manual dexterity test, prior to being assigned to an AGREE program. Operators are equipped with thermostat controlled soldering irons for normal soldering, and resistance soldering irons for soldering in restricted areas.

Wiring and soldering techniques were subjected to intense investigation to keep errors to a minimum. Where assembly processes had called for soldering three wires to the same terminal in one operation, the process was revised to solder the upper, middle, and lower wires individually. Although three operations are substituted for one, it was found that the incidence of no solders and rosin solders was greatly reduced. Specially designed cardboard frames that support cables and prevent them from being flexed during assembly and handling were introduced and have been very successful in preventing broken strands. Thermal stripping of wire is used in many areas to prevent nicking of wire strands and subsequent breakage.

Failure Reporting and Analysis

A major shortcoming of many quality programs is the lack of accurate failure reporting and analysis. Test personnel may treat failure reports, data recording, and tagging failed parts, as secondary tasks. This approach can not be tolerated where AGREE is concerned, since failure reporting and analysis provide the basis for evaluating process controls.

The AGREE document spells out the type of forms that must be maintained during the reliability and longevity tests, and the failed part analysis required. This information is processed into six forms, the most important of which is the Failure Report (Figure 4). The Failure Report is a master which must be completed for every failure. The tester and his supervisor complete their section, and if a component or sub-assembly is involved, send the defective part and the failure master to the Quality Control Laboratory. The Quality Control Laboratory analyzes the part for mechanism of failure and reports its findings. Every failure report is then sent to Reliability and Design Engineering for review and recommendation. If the responsibility for failure is a supplier's, the part and a failure report copy are sent to the supplier for his analysis and corrective action. If the responsibility is RCA's, corrective action is taken by the responsible assembly or test area, or by Engineering. The entire failure reporting cycle is shown in figure 5.

Although the concentration on failure reporting and analysis at the reliability test phase was needed from the standpoint of determining corrective action, it was actually after the fact. The information could be used to prove whether or not equipment met the MTBF requirement and to take action to prevent similiar failures the following months, but could not prevent the manufacturing activity from experiencing an AGREE reject decision should too many failures occur.

At the initial planning stage, it was decided that to provide control and corrective action within each monthly AGREE demonstration, it would be necessary to analyze every part failure from printed circuit testing up to AGREE system testing. Although this was a drastic change from the normal procedure of analyzing only repetitive failures, it has played a major role in helping RCA to fulfill contractual MTBF requirements.

The following are two examples of what AGREE and prior to AGREE analysis can accomplish. One of the first AGREE failures experienced was a film resistor which opened after a prolonged period of temperature cycling. Analysis indicated that the failure was due to a residual strain brought about by the packing density and the restriction placed on the parts by the printed board potting compound. This relationship became an excellent sorting mechanism for the more poorly made resistors. A combined effort by the supplier and RCA Engineering resulted in a new resistor design which eliminated the problem. The important point of this example and other similar ones is that without the pre-AGREE and AGREE environmental stressing, this condition may not have become known until failures occurred in the field. Then a costly and time-consuming retrofit program would have been necessary. By identifying the problem in the factory, corrective action could be made prior to shipment of systems. The above example, however, counted as a failure with respect to the AGREE accept-reject criteria. A second example illustrates how analysis prior to the AGREE test can prevent AGREE failures. Analysis of a wire wound resistor indicated that the leads were insecurely terminated in the rubber material of the resistor's interior. This allowed the lead to rotate, breaking the contact internally. Based on this analysis, 2066 resistors in stock and on printed boards were X-rayed. The findings indicated that 50 resistors had the internal contact broken. The resistors were returned to our supplier for their corrective action as shown in figure 6. Similar failure analyses have resulted in many potential AGREE failures being weeded out prior to the AGREE test.

FAILURE REPORT

DATE 3-29-60   **CONTRACT** AF 33 (700)39000   **EQUIPMENT** ARW-60   **REPORT SERIAL NO.** 0049

1. **TIME OF DAY.** 1315   2. **SYS. SER. NO.** 8   3. **B/B NAME & NO.** Rec. #8   4. **TOTAL OPERATING TIME PRIOR TO FAIL** 392.5   5. **POS. NO.** 4

6. **TEST STEP NO.** Frequency change 5.13   7. **SYMPTOM** Receiver cycles continuously +55 and room temperature.

8. **OTHER FAILURES.** None

(OBSERVED SIMULTANEOUSLY WITH ABOVE)

TROUBLE POS. NO. TX 1001L   **AGREE WITH #7 ABOVE?** Yes   **TEST STAMP** J. Brown

LIMITS CHECKED TP-22-25201

DISPOSITION – SENT TO REPAIR ☒   **READJUSTED** ☐   **RET. TO SYS.** ☐   **DATE & TIME** 3-29-60 1500   **TESTER** B. Smith

A2C resistor R-4 open – Sent receiver #8 to repair

REPAIR TIME & DATE RECEIVED 3-29-60   **TIME STARTED** 1630.

REPLACED PART NAME & CKT. SYM. R-4   **PART NO.** 813723 MFG. ADC Co.

REPLACED WITH NEW ☒   **USED** ☐   **BURN-IN** ☐   **PART NO.** 813723 MFG. " "

MULTIPLE FAILURE

REPLACED PART NAME & CKT. SYM.   **PART NO.**   MFG.

REPLACED WITH NEW ☐   **USED** ☐   **BURN-IN** ☐   **PART NO.**   MFG. 3-30-60

REPAIR STAMP   **INSP. STAMP**   **Q.C. STAMP**   **TIME FINISHED** 1200

QC VERIFICATION Rejection of resistor was verified

1. **TEST EQUIPMENT USED** Wheatstone Bridge, X-Ray, Microscope

LIMITS CHECKED Continuity and Inspection.

COMMENTS & DISPOSITION Resistor returned to vendor for analysis.

See Quality Control Lab, DA-701

2.

RETEST

DATE & TIME 3-30-60 1200   **BENCH** ☒   **TROUBLE** ☐   **SYS.** ☐

TEST POS. NO. TX 1001L   **T.P. USED** TP-24-25201

STEPS RETESTED Channel change – selectivity

ENVIRONMENT – EXPLAIN: Room temperature -55°

DISPOSITION – SENT TO REPAIR ☐   **SYS.** ☒   **ADD. FAILURE REP. #** None

DATE & TIME 3-30-60 2130   **TESTER** J. Brown

ENGINEERING   **REPORT PREPARED BY** Quality Control Engineering Lab

Wire wound resistor is mounted with edge opposite the leads flush with chassis. Insulating coating on resistors was very thin. It was possible for resistor turns to open due to abrasive action and/or grounding thru the thin coating. Corrective action consisted of vendor increasing coating by approximately 1/32" and subjecting each resistor to a 500 volt dielectric test.

All old type resistors have been removed from stock and from built up units.

RECOMMENDATIONS

PART FAILURE CATEGORY 1. **RELEVANT** ☒   2. **NON-RELEVANT** ☐

4/4/20

Figure 4. AGREE Failure Report
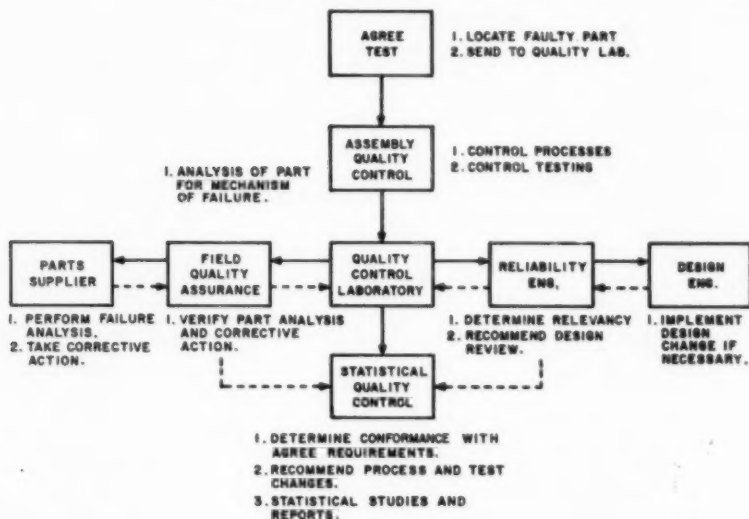
Figure 5. *AGREE Failure Analysis*

A. PRIOR TO CORRECTIVE ACTION

NOTE: TERMINATIONS WERE EMBEDDED IN RUBBERY MATERIAL

B. CORRECTIVE ACTION – PRESENT PROCESS

NOTE: SPOT–WELD TAB IS USED TO TERMINATE RESISTANCE ELEMENT AND PREVENT ROTATION OF TERMINAL SINCE IT IS EMBEDDED IN RIGID EPOXY MATERIAL.
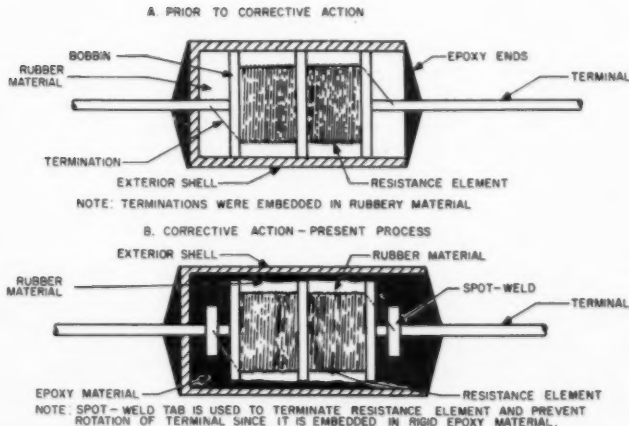
Figure 6. *Example of Pre-AGREE Corrective Actions*

The above examples illustrate how analysis of an initial failure may prove extremely valuable. Most important, however, is that a dual effort is required; first: AGREE test failure analysis to control month to month trends and to identify failures that would normally only show up in field use; second: prior to AGREE test failure analysis to indicate within month trends and provide corrective action prior to the AGREE test.

RESULTS OF AGREE TESTING

The first RCA equipments to be subjected to AGREE were the Airborne Time Division Data Link systems. These equipments provide high speed communication of messages and control information to manned and unmanned aircraft for intercept, tactical control, traffic control, and other modes of operation. They are used in the century series interceptors and the Bomarc missile, and are designated as the ARR-60, ARR-61 and DRR-1.

As of January 31, 1961, eighty-six ARR-61 systems and 77 ARR-60 systems had undergone the AGREE reliability test. Figures 7 and 8 depict the progress made by the ARR-60 and ARR-61 in meeting or exceeding contractual requirements (the DRR-1 curve is not shown as the equipment's MTBF has been 20 times greater than required since the start of production). Except for the ARR-60, the equipments started out meeting the contractual MTBF requirements. The ARR-60 was the first equipment to undergo the AGREE test, and experienced an AGREE Pre-Production reject decision due to a combination of design problems, plus the inexperience of assembly and test personnel with the product. It should be realized that the AGREE test is extremely responsive to problem areas, and one or two problems of a repetitive nature can very quickly cause a reject decision. Fortunately, the descriptive and laboratory analysis that was performed on each failure provided sufficient information so that corrective action could be implemented quickly. The lack of trouble with the ARR-61 and DRR-1 reflects the use of ARR-60 experience to correct potential trouble spots in those systems prior to subjecting them to AGREE.

Experience with AGREE has resulted in many reappraisals of our engineering and manufacturing methods and procedures. Where there had been doubts about the effectiveness of AGREE, there is now confidence in AGREE as an effective means for improving reliability. It provides us with a method which is sensitive enough to quickly detect significant changes in our assembly processes, the processes of our component suppliers, or inadequate engineering.

AGREE experience has enabled us to compress into about three months, the process and design changes that normally required considerable factory, Engineering type test, and field data before they could be initiated. Historically, this same corrective action on non-AGREE equipments has stretched over one or two years and longer.

A comparison can be made relative to the complexity of several equipments produced in the past and their factory achieved MTBF, versus the complexity of the equipments undergoing the AGREE test program, and their factory achieved MTBF and/or their contractual MTBF. This data is presented in Table II. Note that the AGREE equipments are in some cases two to five times as complex as the pre-AGREE equipments, yet have achieved or are required to achieve substantially higher MTBF's. This has been accomplished under environmental stress whereas the pre-AGREE equipments MTBF's were measured under an ambient environment.

Table II — Comparison of Pre-AGREE and AGREE Equipment MTBF

PRE-AGREE EQUIPMENTS	TYPE OF EQUIPMENT	PART COUNT	FACTORY MTBF	CONTRACTUAL MTBF
AN/ARC-21	UHF Airborne Transceiver	2000	200	NA
AN/ARC-34	VHF Airborne Transceiver	1250	250	NA
MA-10	Airborne Fire Control	900	50	NA
MG-10	Airborne Fire Control	10,000	20	NA
AGREE EQUIPMENTS				
AN/ARR-60	Aircraft Time Division Data Link	5900	204	200
AN/ARR-61	Aircraft Time Division Data Link	2200	363	250
AN/DRR-1	Bomarc Time Division Data Link	4000	118	5
TSM-22	Data Link Ground Test Equipment	5600	–	250
TSM-29	Data Link Ground Test Equipment	4500	–	250
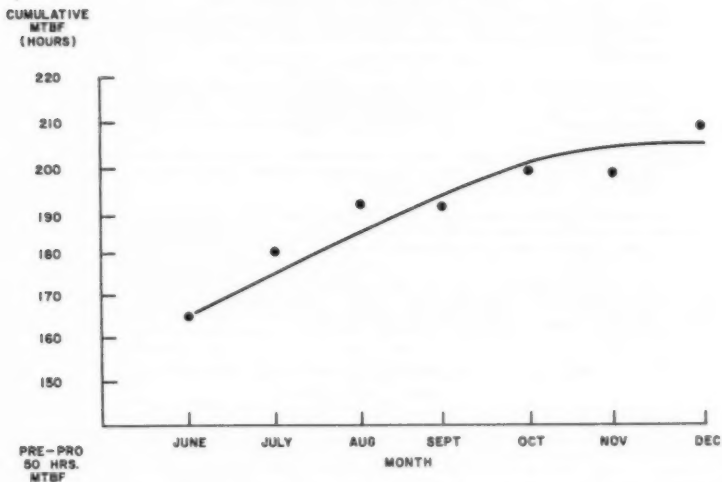
Figure 7. AN/ARR-60 Cumulative MTBF vs Production Month — 1960
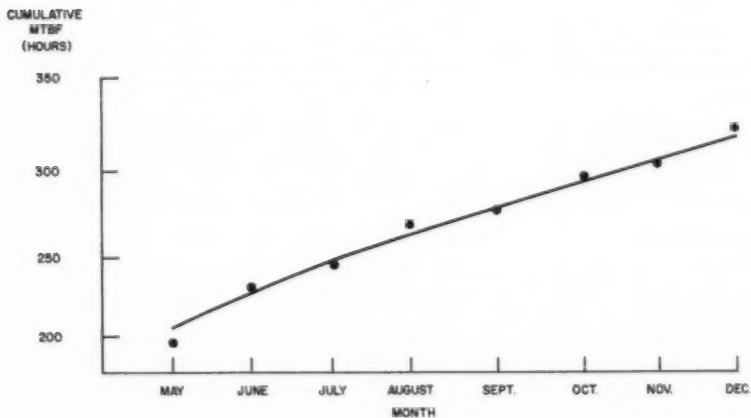
Figure 8. AN/ARR-61 Cumulative MTBF vs Production Month — 1960

OBSERVATIONS

Based on the AGREE testing and analysis performed to date, several significant observations have been made.

1. Temperature is the major discriminatory factor, and the difference in MTBF between the same system subjected to a cycle of –54°C to +55°C, or to a cycle of 0°C to +55°C, can be as great as 4 or 3 to 1. The DRR-1 data link exhibited a MTBF of 118 hours under the former conditions and over 500 hours under the latter conditions.

2. As a corollary to statement one, it is felt that the number of hours the unit is burned-in is not nearly as important as the number of temperature cycles to which the unit is subjected.

3. Low level vibration (25-60 CPS) is not a major factor in debugging transistorized black boxes. Our data indicates that about four hours of vibration is sufficient to weed out any workmanship errors, loose hardware, and parts that may be present.

4. It is most important that the AGREE environmental test cycle be compatible with the equipment design requirements. Disagreement between design and test criteria can cause severe hardship to the contractor.

5. It is most important that suppliers be made aware of the importance of the AGREE program. The need for taking corrective action based on the analysis results of only a single failure must be emphasized. This is a tedious educational process, but one which the contractor must take upon himself in order to assure acceptable results.

6. Table III indicates the predicted, allocated, and actual part failure rates during relia- bility testing. Note that coils and inductors and miscellaneous parts were the only categories failing at a higher rate than expected.

Table III — AN/ARR-60 Averaged Predicted, Allocated and
Actual Failure Rates

PART TYPE		PREDICTED (%/1000 hrs.)	ALLOCATED (%/1000 hrs.)	ACTUAL (%/1000 hrs.)
CATEGORIES	POPULATION			
Blowers and Motors	1	0.090	0.233	-
Capacitors	1205	0.010	0.026	0.037
Diodes	1381	0.019	0.049	0.032
Connectors	77	0.231	0.595	-
Coils and Inductors	105	0.020	0.052	0.42
Filters	5	0.055	0.142	-
Resistors	2455	0.027	0.070	-
Relays	6	0.446	1.153	-
Switches	14	0.520	1.345	-
Transformers	19	0.052	0.134	-
Tubes	15	2.233	5.760	5.96
Transistors	578	0.031	0.080	0.077
Misc. F, Y, etc.	61	0.101	0.261	0.728

NOTE: One failure was due to an unknown cause and could not be assigned. One failure was due to workmanship and was not assigned.

CONCLUSION

AGREE is advantageous to the Contractor. It provides the Contractor with assurance that delivered equipments meet reliability and longevity requirements, resulting in improved Contractor-Customer relations, fewer delinquent contracts, and ultimately lower product cost. It gives the contractor the incentive to upgrade his Quality Control System, and provides the opportunity for subsequent advances in the state of the art.

RELIABILITY - A MANAGEMENT PROBLEM

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Introduction

Behind every case of unreliability in the performance of complex equipment, there is a technical explanation. Yet, the ultimate responsibility for failure to achieve given reliability requirements must be assigned to management.

We have at our disposal, today, sufficiently mature philosophy, methods of approach, technology and statistical methodology to assure the successful achievement of feasible reliability objectives, starting with the design of the product. While some or perhaps all of these elements, as we know them, will go through further stages of evolution to become more efficient and more effective than they are today, we do know that what we have is sufficient. These elements are the ingredients of the so-called reliability programs.

In many commercial product companies, the continued improvement of product design, of manufacturing techniques and processes and of procurement practices has been a matter of normal progress and evolution. In supporting such improvement efforts, management has properly maintained a cautious attitude toward the costs for such efforts. As a matter of record in specific companies, the results of such efforts have paid off handsomely, not only in product quality and reliability, but in very substantial reductions in manufacturing costs.

The most effective of these efforts have gone into a planned and orderly program of sifting out predominant design, process and workmanship deficiencies; of getting to the basic causes of these deficiencies; and of careful follow-up on the corrective action which was indicated. In-house information which is continuously generated on product, process, and workmanship deficiencies, and feedback information from the customer and from the sales force have provided the basis for such efforts.

We have all experienced the benefits of increasing reliability in commercial products such as gasoline engines, electric motors, refrigerators, etc. which have had the advantages of evolutionary improvement, in customer conscious companies. Most of us have experienced too, the continued unreliability in commercial products which fail to recieve the benefits of evolutionary improvement. Products which go through radical re-design every year prove our case.

The Problem

The critical reliability problem arises when revolution, rather than evolution of product design and production processes become the way of life; when size and wieght restrictions are made radically severe; when performance requirements and use conditions are pushed to the frontiers of our technology and experience; and when specified reliability objectives cannot clearly be attained by logical and practicable extensions of existing experience. In general, when our knowledge and experience is limited, we must fill this void with some sort of discipline which will minimize the risks of failure in achieving desired objectives. This is where the formal reliability program enters the picture.

A comprehensive, planned, organized, coordinated and properly manned and funded reliability program can provide utmost assurance that reliability objectives will be achieved under the extenuating circumstances described above. The costs of such programs are not trivial. However, we are familiar with the fact that we can buy time and buy experience whenever we are willing to pay the price. The reliability program is the best thing we can buy to cover our deficiencies in time, knowledge, and experience, in this situation. In the long range, we expect to see the costs of such programs pay off in achieved objectives and we expect, too, that the costs of such programs will diminish as the growth and accumulation of our technical knowledge and experience reduces the

degree of supplementary formal reliability effort which is necessary.

In general, management has shown reluctance to approve the kind of funds necessary to support a comprehensive reliability program. In cases in which the full significance of exotic product specifications was not really understood and in which the needed reliability program was not funded, the ultimate cost of the unreliable product, to the customer, if not to the producer himself, has been many times greater than a full-blown reliability program might have been. The situation has changed somewhat recently in that the customer for high reliability complex equipment, primarily the military services, takes the position now that the required reliability, as specified in the contract, must be demonstrated. At the same time, however, these same customers are indicating their understanding of the reliability problem by their expressed expectation to pay for the necessary supplementary reliability effort.

While a complete dissertation on all the elements of a comprehensive reliability program is not the purpose of this paper, a brief review of some of the major elements will be useful.

Historical Note

Many definitive elements of a reliability effort were formalized in 1957 with the official publication of a rather comprehensive report by the Advisory Group on Reliability of Electronics Equipment (AGREE) under the Office of the Assistant Secretary of Defense (1). This report culminated about seven years of background studies and activities by specialists in both industry and government. Altogether, the report formalizes a philosophy, a set of definitions, a group of technicaland statistical procedures, and a number of organizational and management principles which are considered essential for the understanding and achievement of reliability objectives. A large number of military documents and specifications on reliability, recently issued, follow AGREE recommendations very closely.

The emphasis to-date has been predominantly on electronics equipment for the simple reason that this is where the problems and effects of unreliability have been most severe.

Engineering Responsibilities

In view of the problems which are created by the "revolutions" in product specifications and reliability requirements, it isn't surprising that a major burden of reliability is placed on the engineering activity. The demands and complexities of the engineering job in areas of limited experience have created the need for specific supplementary activities which have been accepted as key elements of a reliability effort. Some of these elements are:

Specification reviews as a means of bringing specialized skills into the problem of establishing completely detailed mutual agreement between the customer and the design engineer on what the product must do, how it must do it, the specific conditions under which it must be done, the certainty that it will be done successfully and any other considerations which can have a bearing on product performance and evaluation. There can be no measure of reliability until all relevant specifications on the product have been completely spelled out.

Design reviews as a means of building assurance that all the specifications have been properly translated into an optimum design and allowing specialists of every concievable kind to contribute his special skills, knowledge, and experience. The anticipation of all possible modes of failure, characteristic to the design, is a job which requires the participation of people who collectively, at least, have experienced all possible modes of failure.

Reliability predictions through systems analyses are the means by which estimates of reliability achievement during desgn are made. Inaccurate as such estimates may be, they provide a relative measure of reliability progress; a means by which areas of reliability deficiency can be identified in the design; a means by which the possible advantages and effects of redundancy, derating of parts, and trade-offs among various requirements can be determined. These predictions are continuously improved as more factual data from hardware evaluation becomes available.

Reliability apportionment to subsystems and components is essential to provide sub-

contracting organizations with specific reliability objectives. Because all components do not functionally contribute equally to overall system reliability and because reliability prediction techniques are only approximations initially and because there may be interface problems which cannot be fully anticipated, the apportionment job is a difficult one and awaits improvements in supporting techniques.

These are just a few of the reliability disciplines which have been evolved to meet the problems arising in the design phase from the fermentation of very complex and exotic product requirements. The critical nature of the design responsibility for ultimate reliability is clear. An upper limit of reliability potential is determined by the engineering design and every effort must be made to optimize it. Statistically designed experiments, computer simulation techniques and other scientific techniques must be used to maximum effectiveness.

While design changes to improve reliability can be are are made at later stages, the severe costs of making such changes during the production phase or even later as retrofits can readily justify the time and costs which are necessary to obtain an optimum design initially. This does not take into consideration the severe maintenance costs which have actually been experienced in the use of sub-standard reliability equipment. The total costs of procurement plus maintenance and repair for low reliability equipment has been shown, by a military agency, to be many times the same total costs for high reliability equipment.

Quality Control and Manufacturing Responsibility

The need for the participation of quality control and manufacturing specialists arises during the design phase and increases as development activity is undertaken. Problems of producibility, tolerancing, measurability, vendor and subcontractor evaluations, hardware evaluation and qualification, test equipment specification and standardization, environmental testing, etc. arise during the design and development phases and require the cooperative efforts of engineering, quality control and manufacturing personnel. Manufacturing problems and deficiencies, too, must be anticipated and prevented before they actually arise.

All the skills, talents, and experience of quality engineering and manufacturing specialists must enter the high reliability situation. Established standards of manufacturing acceptability may require radical revision to meet the newer reliability objectives. During the production phase we hope to maintain the potential design reliability to the utmost. Paralleling the optimization of engineering design, production systems must be optimized to minimize any reduction in the potential inherent reliability of the product.

Techniques which have been helpful in improving production processes have evolved over the past years. However, such techniques alone are often insufficient to achieve the optimum porduction situation. An overall plan of action, taking the total situation into consideration (2) must be formulated. The limited talent which is available for the optimization effort must be used with maximum effectiveness in the areas of maximum potential return. We contribute very little to the optimum situation by reducing the variation on a plating process when the major overall manufacturing deficiency is workmanship.

As a matter of fact, statistics do indicate that a large part of the reliability problem can be attributed to workmanship deficiencies. The manufacturing optimization effort must tkae into cognizance even psychological considerations which may have a bearing on the problem. One such consideration is that of placing maximum responsibility for workmanship on the operator himself. There has been a strong tendency in most companies to place a large share of responsiblity for deficient product on quality control to the extent that true responsibility has, in fact, been removed from the operator. While work conditions, tools, jigs, etc. can influence workmanship and should be improved when necessary, there is no substitute for the direct pressure of responsibility for doing the job right the first time. Such pressures can be applied in a straightforward manner with very rewarding results, (3).

In general, quality engineering and quality control effort must be sharpened and made more effective to meet the challanges of higher reliability. Some interesting criteria to be considered are: Every quality control dollar invested must show a measurable profit. Every potentially profitable dollar must be invested.

Philosophical Considerations

As would be true for any complex problem which has been given so much emphasis and attention, there have been a number of philosophies, some conflicting, on the best way to handle the reliability problem.

One of the earliest, propounded by Lusser emphasized testing to destruction or to failure as the means by which a basic understanding of the mechanism of failure, of the basic underlying chemical and physical phenomena contributing to failure could be obtained. Such basic understanding would necessarily lead to better materials, parts, designs, and higher reliability. But Lusser's philosophy failed to achieve predominance today. There is great merit in his thinking, but it concentrated so heavily on this single basic idea that his approach failed to fill the immediate need for a total reliability program would would give assistance to the design engineer throughout his drawing board activities and then carry through into development, production, evaluation, field use and complete the circle of feedback and corrective action.

Another philosophy has placed major emphasis on the combination of redundancy and high maintainability as the answer to the reliability problem. By incorporating redundancy in potentially low reliability areas of the system and by designing for ease of replacement and maintenance, high reliability equipment can supposedly be produced with less effort and lower cost. The opponents to this approach question the hypothesis of lower costs, noting the heavy replacement and repair costs on the relatively frequent failures of low reliability components as well as the added problems of inventory, transportation and handling of increased numbers of spare parts, etc. Another argument suggests that such an approach reduces the pressures for scientific and technological progress which must inevitably provide the reliability breakthroughs of the future and much higher reliability at much lower cost.

The predominant philosophy today is the one which is presented in the AGREE report. It provides all the elements which are needed for a total reliability program forming the closed loop between initial design and field failure feedback. It is apparently logical and practicable. It has brought about excellent results. However, it has some debatable aspects too. It places heavy emphasis on reliability prediction which in turn is dependent on a knowledge of the failure rates of parts under various conditions of application. In recognition of the parts problem the AGREE report recommended and was followed by a special study on this problem (4). A very heavy expenditure of time, effort and test equipment must be made in the measuring of failure rates of parts. It can be argued that if a reasonable fraction of this parts testing effort would be devoted to statistically engineered investigations, designed to optimize and improve part designs and manufacturing processes, then failure rates could be reduced and the groundwork laid for greater reliability progress in the future.

It is likely that some combination of the many philosophies will evolve in the near future with enough variations to cover a large variety of basically different problems.

Conclusion

It can be seen that the overall effort for a comprehensive reliability program is tremendous even though we haven't discussed many important aspects such as: parts evaluation and procurement, coordination of subcontractor reliability efforts, failure reporting systems, failure data analysis, failed parts analyses, reliability education and others. Above all, the coordination of all the activities and functions which relate to the reliability effort can make the difference between a successful program and an unsuccessful one.

Many difficult issues must be resolved such as:

The determination of the most effective and appropriate philosophy for the company and its future.

The most effective delegation of responsibility for the reliability effort in its various phases.

The optimum allocation of funds which are both necessary and sufficient for both the immediate objectives and the long range objectives of the company.

These and other issues must be resolved by management. In considering the total

picture it becomes obvious that the struggle for high reliability is at least as great a challange to management skills as it is to technical skills. The days of evolutionary progress and development can be properly remembered with nostalgia.

References

(1) Advisory Group on Reliability of Electronic Equipment, Office of the Assistant Secretary of Defense (Research and Engineering), "Reliability of Military Electronic Equipment," U. S. Government Printing Office, June 1957.

(2) Budne, T. A., "SQC Can Be Made More Effective," Industrial Quality Control, Vol. XV, No. 6, December 1958.

(3) Budne, T. A., "Cost-Shooting a Manufacturing Operation," Transactions of Tenth January Conference, Hamilton-Middletown-Cincinnati Sections of ASQC, January 1961.

(4) Ad Hoc Study Group on Parts Specification Management For Reliability, Office of the Director of Defense Research and Engineering and Office of the Assistant Secretary of Defense, Supply and Logistics, "Parts Specification Management For Reliability," U. S. Government Printing Office, May 1960.

RELIABILITY REQUIREMENTS IN PARTS SPECIFICATIONS

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SUMMARY

Reliability is a quality characteristic that defies definition and, for this reason, is a requirement that is difficult to describe under any circumstances. It is even more difficult to describe the reliability requirement in a specification for the kind of component part that is commonly referred to as the "hardware" which collectively comprises the building blocks of equipment.

This paper discusses the problem of developing a procedure for incorporating reliability assurance provisions into specifications for component parts. Two major problem areas are examined: (1) the problem of developing a testing program that not only is capable of identifying the reliability level which a part can be expected to meet but also is capable of assuring conformance to this level when so specified by the purchaser; and (2) the problem of fitting such a flexible testing program into the inherently inflexible provisions of a part specification.

INTRODUCTION

The purpose of this paper is to discuss the problem of developing a procedure for incorporating reliability assurance provisions into specifications for those many component parts, commonly referred to as "hardware," which collectively comprise the basic building blocks of any major item of equipment. During the past two or three years a great amount of effort has been expended on the problem of developing a reliability assurance provision that might be readily incorporated into the many existing part specifications. Of the many methods proposed for specifying reliability, however, only one offers a solution both to the problem of the very large sample sizes required for life testing and to the problem of applicability to specifications for a wide variety of products.

The reliability assurance provision discussed in this paper might be described as a multilevel reliability requirement inasmuch as it proposes to establish more than one level of quality and reliability in each specification. The primary purpose of this paper is to examine two problems related to the development of such a multilevel reliability requirement: (1) the problem of developing a life testing procedure which calls for reasonably small sample sizes and still is capable of not only disclosing the reliability level a part can be expected to meet but also assuring conformance to this level when so specified by the purchaser; and (2) the problem of fitting such a flexible testing procedure into the inherently inflexible quality assurance provisions of a component part specification.

THE MULTILEVEL RELIABILITY REQUIREMENT

The basis for the multilevel reliability requirement is the fact that component parts manufactured to existing specifications are often much more reliable than these specifications require them to be. It is impossible, however, to identify these reliable parts by using the test procedures called for in existing specifications since these procedures can do no more than distinguish between product that exceeds minimum performance requirements and product that does not. The only way to identify those lots which are significantly more reliable than required by the specification is to retest each lot using a larger sample than called for by the specification.

This additional testing would not be necessary, of course, if the specification provided some means by which a purchaser would have the choice of a number of different sample sizes. Each purchaser could then choose the size needed to assure the level of reliability he desired. Such a proposal was made in a paper presented at the Fifth
(1)
National Symposium on Reliability and Quality Control and was subsequently incorporated into the quality assurance provisions of a general specification for semiconductor devides, MIL-S-19500B. This first version of the multilevel reliability requirement appears in MIL-S-19500B in the following form:

40.7.2.1 Table IV shows the minimum sample sizes necessary to assure
a maximum failure rate in percent per thousand hours, in the lot represented,
with a confidence level of 90 percent for various failure acceptance numbers.

Table IV - Minimum size of sample to be tested for
1,000 hours to assure a failure rate no greater
than the maximum failure rate with 90% confidence.

Maximum Failure Rate	50	20	10	5	2	1	0.5	0.2	0.1
Accept. Number	Minimum Sample Sizes								
0	5	12	24	47	116	231	461	1,152	2,303
1	9	20	40	79	195	390	778	1,946	3,891
2	12	28	55	109	266	533	1,065	2,662	5,323
3	15	35	69	137	333	668	1,337	3,341	6,681
4	19	42	83	164	398	798	1,599	3,997	7,994
5	22	49	97	190	462	927	1,855	4,638	9,275
6	25	56	110	217	528	1,054	2,107	5,267	10,533
7	28	63	123	243	589	1,178	2,355	5,886	11,771
8	31	70	136	269	648	1,300	2,599	6,489	12,995
9	34	76	149	294	709	1,421	2,842	7,103	14,206
10	37	83	161	319	770	1,541	3,082	7,704	15,407
20	--	--	---	---	---	2,705	5,410	13,525	27,050
40	--	--	---	---	---	4,940	9,880	24,700	49,400

The above described version of the multilevel reliability requirement undoubtedly
improved the original version of MIL-S-19500 but is obviously impractical. First, the
sample sizes called for in the above table are much too large for sampling component
parts that quite often are purchased in smaller lots than the sample sizes called for
in the table, although it should be pointed out that the only alternative to such large
sample sizes is less reliability assurance.

A second inadequacy in this type of reliability requirement is that there is no
provision for ascertaining whether the product to be tested is designed to meet the
specified failure rate level. In effect, this version of the multilevel reliability
requirement proposes to "test reliability into the product."

New Concept Details
       The second phase in the development of the multilevel reliability requirement is
                                             (2)
illustrated in the report   of the Ad Hoc Study Group on Part Specifications Manage-
ment for Reliability. The Study Group proposal, while it did not solve the basic prob-
lem, included two new concept details related to certain essential elements of the
multilevel reliability requirement. One of these details was a proposal to "certify"
each supplier as an approved source of supply for electronic parts according to the
average level of reliability exhibited by his product. The second detail was a propos-
al to tie in retention of "certification" at a failure rate level with "acceptance"
life testing as a means for reducing sample sizes. These two concept details are re-
flected in a "Reliability Level Qualification" requirement and a sequential sampling
procedure developed for the improved multilevel reliability requirement examined in
this paper.

The third phase in the development of the multilevel reliability requirement was
initiated when the Ad Hoc Study Group discontinued the second phase in order to prepare
their report. It was apparent that further study was needed to complete the require-
ment and a manual of instructions would be needed as a guide for revising existing
specifications. This task was undertaken immediately by members of the staff of the
Quality Control and Reliability Division, Office of the Assistant Secretary of Defense
(Installations and Logistics), who had participated in the work of the Study Group.
At the time this paper went to print an interdepartmental task group was working on a
draft of a proposed manual of instructions illustrated with a prototype specification
embodying a multilevel reliability requirement based on the following concepts:

(1) A provision establishing a series of reliability levels, the lowest level based on the performance characteristics of product in current production.

(2) A provision for "acceptance" life testing which assures at the 90% probability level that those lots passing the test either meet or exceed the reliability level for which the product is qualified.

(3) A provision for the systematic accumulation and evaluation of "acceptance" life test data to provide an estimate of the reliability level actually attained as a basis for "qualifying" each supplier's product according to the level of reliability it can be expected to meet.

(4) A provision for adjusting environmental requirements according to the reliability level for which a product is qualified.

(5) A provision for the use of a modified sequential sampling plan at the higher reliability levels to reduce "acceptance" life test sample sizes to a practical minimum.

<p style="text-align:center">SPECIFICATION REQUIREMENTS</p>

Before proceeding with this discussion, it might be well to examine briefly some of the restrictions that the "hardware" type of component part imposes on the specification requirements:

(1) The part may be manufactured by many suppliers, each producing the same part insofar as size, shape, and minimum performance are concerned but a very different part in terms of material, design, construction detail, and maximum performance. The specification must assure interchangeability, quality and reliability without imposing restrictions either on the method of manufacture or any action necessary for product improvement.

(2) The part may be used in a wide variety of equipments, under various combinations of environmental stress, under continuous or intermittent operating conditions, and under full or only a partial load. The specification not only must provide assurance that the part will perform its intended function satisfactorily under any of these conditions but also must provide this assurance with one standard testing procedure.

(3) The part may be manufactured either under mass production conditions or in job lots and may be purchased in either small or large lots. The specification must provide a sampling procedure that assures conformance equally well under any of these conditions.

(4) The same part may be produced in many variations that are not interchangeable with each other but not necessarily different with respect to those design details that might affect reliability or capability to withstand environmental stresses. In order to reduce performance testing to a practical minimum, the specification must classify these variations into appropriate family groups such that the testing of any member of the family can be used to evaluate the performance of the family as a whole.

With the above considerations in mind let us now proceed to examine the multilevel reliability requirement as it appears in a revised specification for a typical component part.

Revised Version of MIL-C-25C

The specification selected to illustrate the multilevel reliability requirement in this paper is a general specification for capacitors, MIL-C-25C, which is being used as an illustration in the previously referred to manual of instructions for revising specifications. This specification covers several hundred variations of a paper or paper-plastic capacitor, hermetically sealed in a metallic case. The product it covers is just about the most typical piece of "hardware" that might have been chosen to prove the practicability of the multilevel reliability requirement. As previously explained, the specification should permit each supplier to produce the best capacitor that he can and should not restrict the choice of material, design and construction detail any more than necessary. Actually, the original version of MIL-C-25C imposed very few restrictions on such details and required relatively little revision in this respect. However, the basic principle is clearly expressed in the following requirement:

3.3 Material, Design and Construction Detail. This specification prescribes only those material, design and construction details required to assure interchangeability between units of product. All other such details shall be selected by the supplier and shall be suitable for the intended purpose.

Qualification Requirements

From the standpoint of reliability, the above requirement is important because it removes any restriction that might prevent suppliers from making design changes to improve product performance. But, in removing these restrictions, the requirement opens the door to design changes that may adversely affect performance. In addition, the requirement may adversely affect procurement activities because deliveries on a contract may be delayed whenever a supplier has trouble selecting suitable design detail. Thus, the above requirement must be supported by two additional specification provisions. One provision should give each purchaser some means for determining before a contract is placed that difficulties related to the selection of unspecified design detail will not cause unusual delivery delays. The second provision should provide protection against the adverse effect of design changes. These two provisions have been included in the revised version in the form of the following "qualification" requirements:

3.2 Qualification. At the option of the procuring activity, awards will be made for only those products that, prior to the bid opening date, have been tested and qualified for inclusion in the applicable Qualified Products List.

3.2.1 Initial Qualification. Initial qualification shall be required for product required to meet the minimum quality and reliability level established by this specification.

3.2.2 Periodic Qualification Evaluation. Product to be furnished under this specification shall be required to pass a periodic qualification evaluation test to evaluate the ability of units from current production to withstand the environmental stresses applicable to the reliability level for which the product is qualified.

3.2.3 Reliability Level Qualification. Product to be furnished under this specification shall be required to prove that its potential reliability is equal to or higher than the reliability level it is expected to meet.

Classification of Inspections

Inasmuch as the above qualification requirements are intended to evaluate the suitability of material, design and construction details, it is important that these requirements consist of tests specifically designed to accomplish the desired evaluation. Some tests in a specification are intended to check the suitability of design but others are not. It is possible to distinguish between them by classifying the examinations and tests in a specification into the following three functional groups.

(1) Group 1, Conformance Inspections - These inspections are performed to ascertain that product conforms to standards established by the design. Each examination or test in this group involves a measurement or comparison to a design standard.

(2) Group 2, Environmental Tests - These tests are performed to ascertain whether product conforming to design standards (per Group 1 above) can withstand certain environmental conditions to which it may be subjected in operation. These tests include environmental conditioning (e.g., subjection to shock, vibration, temperature variation, etc.) during or after which the Group 1 inspections are repeated to detect any change in the product.

(3) Group 3, Performance Tests - These tests are intended to ascertain whether product conforming to design standards is capable of functioning satisfactorily throughout its projected life. These tests are characterized by a specified number of hours or cycles of functional operation during or after which certain Group 1 inspections are repeated to detect any changes in the product.

It is readily apparent that the examinations and tests in only two of the above described functional groups are capable of detecting design deficiencies. Group 1, Conformance Inspections can be used to determine whether the product conforms to a design

standard but cannot be used to determine whether the standard itself is suitable. Thus, the examinations and tests comprising the qualification requirements should consist of the Group 2, Environmental Tests and Group 3, Performance Tests.

The following is an example of the above described classification when applied to the examinations and tests in specification MIL-C-25C:

4.1.1 Classification of Inspections. The examinations and tests that collectively comprise the quality and reliability assurance provisions of this specification are classified as shown in Table IV.

Table IV Classification of Inspections

Conformance Inspections, Group 1
Subgroup 1:
     Dimensional and visual, internal
     Material
     Dimensional and visual, external
Subgroup 2:
     Dielectric withstanding voltage
     Insulation resistance
     Capacitance
     Seal
     Quality Factor

Environmental Tests, Group II
Subgroup 1:
     Barometric Pressure
     Vibration
     Salt Spray
     Temperature Cycling
     Immersion Cycling
Subgroup 2:
     Terminal strength
     Moisture resistance
     Shock

Performance Tests, Group III
     Capacitance change with temperature
     Life

When examinations and tests having a common purpose are grouped as shown in the above specification requirement, it is possible to specify inspection procedures that assure each group will perform its intended function. The following principles indicate the type of procedure that should be specified:

(1) Conformance inspections should be planned to detect defects which may be acquired at any time during the manufacturing process.

(2) Environmental tests should be planned to detect design errors. These errors may be generated before production begins and at any time a design change is made.

(3) Performance tests are intended to detect limited performance potential caused by certain combinations of normal variations in design and construction detail. Undesirable combinations of these variations may be generated either by design error or by the manufacturing process, therefore, the performance tests should be planned in the same manner as conformance inspections.

It should be apparent from the preceding discussion that the new reliability assurance provision involves no new test methods or inspection procedures. However, it is important that all elements of the existing quality assurance provision be closely coordinated into an effective testing program, for each element has a direct effect on the amount of life testing required. For this reason the several elements of the quality and reliability assurance provision have been classified as shown in the following requirement in the revised version of MIL-C-25C:

    4.1.2   Classification of assurance provisions. The quality and reliability assurance provisions are classified as follows:

         (a)   Initial Qualification. See 4.2
         (b)   Quality Conformance Inspection. See 4.3
         (c)   Reliability Conformance Testing. See 4.4
         (d)   Periodic Qualification Evaluation. See 4.5
         (e)   Reliability Level Qualification. See 4.6
         (f)   Test Methods. See 4.7.

Initial Qualification

    Initial qualification requirements are based either on existing specification requirements or on characteristics of product in current production. For this reason, the initial qualification requirement may establish a minimum performance level well below the current state of the art. However, it is not important that the minimum performance level may be too low inasmuch as the multilevel reliability requirement provides for additional higher levels. Product that exceeds this minimum level will, of course, be identified according to the level it can be expected to meet. The following example is the Initial Qualification requirement in the revised version of MIL-C-25C:

    4.2   Initial Qualification.

    4.2.1   Purpose. The purpose of initial qualification is to assure that material, design and construction detail selected by the supplier is capable of withstanding the minimum environmental requirements of the specification.

    4.2.2   Granting of initial qualification. Initial qualification shall be granted on the basis of objective evidence that the product has been subjected to and has passed the tests specified for initial qualification. A test report, certified by a responsible official of the supplier, may be considered as such objective evidence.

    4.2.3   Combined qualification. Initial qualification shall be granted for all sizes within a style if the largest size in the style passes the initial qualification tests.

    4.2.4   Initial qualification sample. The sample size for initial qualification shall be in accordance with Table 5. All units in the sample shall be the same item number.

    4.2.5   Initial qualification tests. Capacitors shall be subjected to the tests specified in Table 5 in the order shown.

<center>Table 5.   Initial Qualification Tests</center>

Test	Sample Size	Failures Allowed
Flashpoint		
Environmental Tests		
Subgroup 1		
Barometric Pressure		
Vibration	} 6	} 1 }
Salt Spray		
Temperature Cycling		
Subgroup 2		
Terminal strength		
Moisture resistance	} 6	} 1 } 1
Shock		
Performance Tests		
Capacitance change		
Life	12	1

Reliability Level Identification

When a multilevel reliability requirement is incorporated into a specification, some provision must be made for marking parts to show the reliability level they can meet. The method for accomplishing this identification is illustrated in the following example of a revised specification requirement:

1.2 Item number. Each capacitor covered by this specification is identified by an item number in the following form:

CP	25/05	N	273	K
Type	Style	Reliability Level	Capacitance	Capacitance Tolerance

1.2.1 Type. The code letters CP identify one type of direct current, paper or paper-plastic dielectric, fixed capacitors hermetically sealed in metallic cases.

1.2.2 Style. The style is identified by the number of the detail specification. Capacitors of the same style are alike with respect to voltage rating, circuit, configuration, capacitance change, terminal, and insulation resistance.

1.2.3 Reliability levels. The reliability level is identified by a single letter in accordance with Table 1. The failure rate shown for each level is based on two assumptions: (1) the distribution of time to failure is exponential, and (2) the life acceleration factor is 5 for tests at 140% of rated voltage and does not differ between the products of different suppliers.

Table 1. Reliability Levels

Code Letter	Failure Rate in % per 1000 hours
M	31 %
N	6 %
O	1.5 %
P	.4 %
Q	.1 %

Although numerical values for failure rate are shown in Table 1, it should be pointed out that these values are only estimates based on assumptions and are shown for information purposes only. The values shown in the table were computed in the following manner:

Problem: Compute the failure rate in % per 1000 hours which will be rejected 9 out of 10 times by the sampling plan for the life test in the Initial Qualification requirement.

Given: Sample size, n = 12   Acceptance number, c = 1
Length of test, t = 250 hours

Assume: Distribution of time to failure : Exponential
Acceleration factor : 5

Solution: Let the failure rate = R
Let % failures at time t = p_1

From tables of Poisson's Exponential Binomial limit:
When c = 1, there is a 90% probability of rejecting p_1
when $np_1 = 3.9$

Since n = 12, $p_1 = 3.9/12 = 0.325$

and $e^{-\frac{Rt.5}{1000}} = 1 - p_1 = 0.675$

From Tables of the exponential function:
when $e^{-\frac{Rt.5}{1000}} = 0.675$, $\frac{Rt.5}{1000} = 0.393$

Solving for R,   R = 0.31
        or   R = 31% per 1000 hours.

Quality Conformance Inspections

Conformance inspections are performed to ascertain that product conforms to stand-
ards established by the design. Inasmuch as practically all material, design and con-
struction details are selected by the supplier, conformance inspections can be speci-
fied in general terms only. The following is an example of the revised conformance
inspection requirement:

4.3 Quality Conformance Inspection. Conformance to quality require-
ments shall be assured by subjecting the product to the examinations and
tests comprising the Conformance Inspections, Group 1, of Table 4.

4.3.1 Point of inspection. Conformance inspections shall be per-
formed at whatever point in the manufacturing process is most suitable.

4.3.2 Conformance inspection sampling. If conformance inspections
are performed on a sampling basis, the sampling procedures used shall be
consistent with the sampling requirements specified for reliability con-
formance. (See 4.4).

Reliability Conformance Tests

It is not the intent of this paper to propose a definition for reliability but it
is necessary to define the term "reliability level" as used herein. The reliability
level is a quantitative requirement for reliability regardless of the fact that it can-
not be expressed in terms of a numerical value. Whether the failure rate for levels M
and N are 31% and 6% is immaterial provided level N is lower than level M. Whatever
the true failure rate for each of these levels, the following statement can be made re-
garding the difference between these two levels and also any other pair of adjacent
levels:

"If the reliability level of a lot is such that an
M level sample will not pass the life test only 5 times out
of 100, an N level sample from the lot will not pass the
life test 90 times out of 100."

The reliability conformance element of the quality assurance provision is designed
to assure conformance of individual lots to the level of reliability for which a part
has been qualified. As indicated in the following example of the reliability conform-
ance requirement, a sample is tested from each "inspection lot."

4.4 Reliability conformance. Conformance to reliability require-
ments shall be assured by subjecting the product to the life test element
of The Performance Tests, Group III, of Table 4.

4.4.1 Life test sample. A sample shall be selected at random from
each inspection lot which has passed conformance inspection requirements.
Samples shall be selected in accordance with Table 6. The table lists
five sample sizes and corresponding acceptance numbers for each relia-
bility level. Choice of sample size is optional provided (1) the sample
size is selected before the life test begins and (2) the sample size
selected is one of the five sizes listed for the reliability level the
product is expected to meet.

Table 6. Life Test Sample Sizes

Acceptance Number	Sample Sizes Applicable to Reliability Level		
	M	N	O, P and Q
0	7	29	
1	12	50	
2	16	68	(See 4.4.3)
3	21	85	
4	25	101	

4.4.2 Inspection lot. The life test sample shall be selected at random from an inspection lot consisting of capacitors of the same style, manufactured as a continuous production run. Inspection lots may also be formed by combining ⋯ · more production runs provided that all capacitors in the lot are the same item number.

The sampling plans specified for Levels M and N are Lot Tolerance Percent Defective (LTPD) type sampling plans derived in the following manner:

Step 1, Sampling plan for Level M

Given: n = 12 and c = 1 from Table IX of MIL-C-25C
     and t = 250 from 4.6.14 of MIL-C-25C
     Assumed acceleration factor = 5:1 at 140% of rated voltage.

From tables of Poisson's Exponential Binomial Limit:

np_1 = 3.9   when P_1 = .10 and c = 1

p_1 = 3.9/12 = .325   when n = 12

Using p_1 = .325 and values for np_1 from the Poisson tables:

c	np_1	p_1	np_1/p_1	n
0	2.3	.325	7.1	7
1	3.9	.325	12.0	12
2	5.3	.325	16.3	16
3	6.7	.325	20.6	21

With this type of sampling plan, each of the five sample sizes listed and its corresponding acceptance number will reject 90% of the time the same reliability level that would be rejected 90% of the time by the n = 12, c = 1 sampling plan in the existing specification.

Step 2, Sampling plans for Levels N, O, P and Q

By a fortunate coincidence, a minimum amount of life test data is required to distinguish between adjacent reliability levels when p_0 for the largest sample size at the lower level is made p_1 for the next higher level.

From the Poisson tables: When c = 4, np_0 = 1.97

The largest n at the M level = 25

Therefore p_0 = 1.97/25 = .0788 = p_1 , N level.

Step 1 can now be repeated to compute the same sizes for the N level and the procedure repeated to compute the sample sizes for the O, P and Q levels. The sample sizes for these four levels are shown in the following table.

Sample Sizes Computed per Steps 1 and 2

Acceptance Number c	Sample sizes corresponding to Reliability Level				
	M	N	O	P	Q
0	7	29	121	478	1940
1	12	49	200	812	3290
2	16	67	272	1010	4470
3	21	85	343	1390	5650
4	25	101	409	1660	6740

The above tabulation of sample sizes illustrates the rapid increase in sample sizes from one level to the next. At some point, such as level O in the above tabulation, the sample sizes computed in accordance with Steps 1 and 2 become impractically large.

Sequential Sampling Procedures

The next step, therefore, is to specify a different type of sampling procedure for the O, P and Q levels. Depending on the product, it may be possible to lengthen the life test or to make the test conditions more stringent, which would permit the use of smaller sample sizes at the O and possibly P levels. But, as shown by the above tabulation, the sample sizes increase so rapidly from one level to the next that even this alternative is not completely satisfactory.

The only recourse, then, is to develop a plan which may not provide as much protection as the plans computed in Steps 1 and 2 but approaches this level of protection without increasing sample sizes. This objective can be attained by the following procedure:

(1) Use the N level sampling plan to "reject" lots. This assures a 90% probability that no lots will be considered for acceptance at the O, P, or Q levels that might exceed the N level.

(2) Before initiating sampling at the O, P, or Q level, require the product to "qualify" for the level by proving, at a 98% probability level, that the average level met by a sequence of lots was equal to or better than the level for which the product is to be qualified.

(3) Specify that the lot is to be marked as meeting the level for which it is qualified only if statistical analysis proves that this lot and a specified number of lots that preceded it have averaged, at the 90% level of probability, at or above the level for which the product is qualified.

Mathematical Computations

Given: At the O level, $p_1 = .0195$ and $p_0 = .00481$

Problem: Compute the reject line for a sequential sampling plan such that:
(1) There is no more than a .05 probability of rejecting when lot reliability is p_0 or better.
(2) There is at least a .90 probability of rejecting when lot reliability is p_1 or worse.

Solution: The equation for the reject line is

$$F = a + bN$$

Where $a = \dfrac{\ln(1 - p_1) + \ln(1 - p_0)}{\ln p_1 - \ln p_0 + \ln(1 - p_0) - \ln(1 - p_1)}$

And $b = \dfrac{\ln(1 - p_0) - \ln(1 - p_1)}{\ln p_1 - \ln p_0 + \ln(1 - p_0) - \ln(1 - p_1)}$

When the values $P_0 = .05$, $P_1 = .90$, $p_0 = .00481$, and $p_1 = .0195$ are substituted in the above equations,

$$a = 2.05 \text{ and } b = .011$$

and $F = 2.05 + .011N$

Equations for levels P and Q are derived in a similar manner by substituting the values for p_0 and p_1 that apply to these two levels.

The requirement describing the sequential sampling procedure for levels O, P and Q, as it might appear in a specification, is illustrated in the following example:

4.4.3 Sampling for Reliability Levels O, P and Q. Samples for life testing at levels O, P and Q shall be selected as for level N.

4.4.4 Lot rejection. If the number of failures exceeds the acceptance number for the sample size, the inspection lot shall be rejected. Rejection shall be final and rejected lots shall be segregated to preclude mixing capacitors in any other lot.

4.4.5 Reliability level identification. If a sample passes the life test and the capacitor is qualified at level M or N, the inspection lot shall be marked accordingly. If the inspection lot consists of capacitors qualified for levels O, P or Q, the identification marking to be applied shall be determined in accordance with 4.4.6 and 4.4.7.

4.4.6 Tabulation of life test data. For capacitors qualified at levels O, P and Q, identification marking shall be determined on the basis of the results from a series of life tests. For this purpose, the results of life tests from both rejected and accepted inspection lots shall be tabulated, in the order in which the tests are performed, on a form similar to Figure 1. A separate tabulation shall be maintained for each style.

4.4.7 Identification marking, levels O, P and Q. When an inspection lot is "accepted" by the life test sample, it shall be marked either at the level for which the capacitor is qualified or at the next lower level, depending on the process average for the last ten life test samples. After the data for the last sample tested is entered in the tabulation per 4.3.2, the totals for the last ten entries in the sample size and failures columns are summarized and the permissible number of failures computed by applying the appropriate equation in Table 7. If the actual number of failures exceeds the permissible number, the lot shall be marked at the level next lower than the one for which the capacitor is qualified.

Table 7. Determination of Reliability Level

Reliability Level	Permissible Failures, F, for Total Samples Tested, N
O	$F = 2.04 + .001N$
P	$F = 2.07 + .0026N$
Q	$F = 2.06 + .00066N$

Periodic Qualification Evaluation

This element of the quality assurance provision is intended to ascertain whether the design of product from current production is capable of withstanding specified environmental stresses. Periodic qualification evaluation consists of the tests in Group II, Environmental Tests. These tests can be performed periodically because they are intended to provide information regarding the capability of the design which, normally, is not subject to frequent or extensive changes.

As an element of the multilevel reliability requirement, periodic qualification evaluation is designed to evaluate design improvement that increases the capability of a part to withstand environmental stresses. Although the various component parts used in an equipment are subject to the same environmental stresses, existing specifications do not specify uniform requirements for these parts. The multilevel reliability requirement provides for such uniformity as indicated by the following examples of the new specification requirements:

3.4 Environmental conditions

3.4.1 Environmental conditions. Capacitors covered by this specification shall operate satisfactorily after they are subjected to the following environmental conditions:

Table 3. Environmental Conditions

Environmental Conditions	Reliability Level				
	M	N	O	P	Q
Salt Atmosphere					
Hours	48	96	96	96	96
Temperature Cycling					
High °C	85	125	125	125	125
Low °C	-55	-55	-65	-65	-65
Moisture Resistance					
Cycles	10	10	10	10	10
Vibration					
Cycles/second	10-55	10-2000	10-2,000	10-2,000	10-2,000
Acceleration (g)		15	15	15	15
Shock					
Acceleration (g)		50	50	50	50
Milliseconds		11	11	11	11
Barometric Pressure					
Inches Hg.	3.44	1.31	0.315	0.043	0.043
Altitude Ft.	50,000	70,000	100,000	150,000	150,000

4.5 Periodic Qualification Evaluation

4.5.1 Purpose. The purpose of periodic qualification evaluation is twofold: (1) to detect any adverse effect on performance resulting from changes in material, design and construction detail; and (2) to verify superior performance capability indicated by life testing results.

4.5.2 Qualification evaluation tests. Capacitors shall be subjected to the tests specified in Table 8 in the order shown.

Table 8. Periodic Qualification Evaluation Tests

Tests	Sample Size	Acc. No.
Environmental Tests		
Subgroup 1		
Barometric pressure		
Vibration	} 6	} 1
Salt spray		
Temperature cycling		} 1
Subgroup 2		
Terminal strength		
Moisture resistance	} 6	} 1
Shock		
Performance Tests		
Capacitance change	12	1

4.5.3 Selection of sample. A sample of capacitors shall be taken from production each month for each style of capacitor in production during the month. The sample size for each test group shall be in accordance with Table 8.

4.5.4 Test method. The test method applicable to the level for which the product is qualified shall be as specified in Table 8.

4.5.5 Test report. A report for each Periodic Qualification Evaluation test, certified by a responsible official of the supplier, shall be submitted to the qualifying agency together with the report

required by 4.6.2.

4.5.6 Initial test at higher level. When application is made for qualification at a higher reliability level, a test report shall be submitted to the qualifying agency as evidence that the product has been subjected to and has passed the Periodic Qualification Evaluation test applicable to the higher level.

Reliability Level Qualification

Reliability level qualification is designed to serve two purposes. First, it provides the means for determining before testing begins whether the part is designed for the reliability level it is expected to meet. Secondly, the controls built into the qualification requirement permit the use of very small samples for reliability conformance testing. The requirement, as it might appear in a specification, is illustrated by the following example:

4.6 Reliability Level Qualification

4.6.1 Purpose. The purpose of Reliability Level Qualification is to assure that the potential reliability of a design is equal to or higher than the reliability level it must meet to pass Reliability Conformance tests.

4.6.2 Granting of qualification. A product shall be qualified for a higher reliability level when a summary of life test data obtained from Reliability Conformance tests indicates that the average reliability over a specified number of test hours is equal to or higher than the next level.

4.6.3 Summary Report of Life Test Data. The supplier shall summarize life test data on a form similar to Fig. 2. A separate summary report shall be prepared for each style of capacitor produced by the supplier during the summary period. Summary reports shall be forwarded to the qualifying agency as of the last day of the calendar month.

4.6.4 Amount of data in summary report. Table 9 shows the minimum amount of life test data required for a statistical determination that a product meets a reliability level. When an application is submitted for qualification at a higher level and insufficient life testing has been performed during the summary period to provide the amount of data called for by Table 9, data from preceding periods may be included in the summary report.

4.6.5 Application for qualification. Application for qualification at a higher level may be made whenever application of the appropriate equation in Table 9 shows that the permissible number of failures is not exceeded. The application for qualification shall be accompanied by a test report of the Periodic Qualification Evaluation tests performed in accordance with 4.5.6.

4.6.6 Revocation of Reliability Level Qualification. If the number of failures during any summary period exceeds the maximum number permitted by the applicable equation in Table 9, qualification shall revert to the next lower level.

4.6.7 Extended life tests. At the option of the supplier, any part of the sample to be subjected to the life test may be designated for continued testing in accordance with the Extended Life Test requirement, 4.7. Data from all extended life tests shall be included in the Summary Report of Life Test Data, and shall be used for the statistical analysis to determine whether the product should retain its qualification, lose it, or be qualified for a higher level.

Table 9. Control Limits for Qualification
at Specified Reliability Levels

Relia-bility Level	Minimum No. of test hrs. required for analysis	Maximum No. of Failures permitted during T, total test hours, to qualify	Maximum No. of Failures permitted during T, total test hours, to retain qualification
N	13,000	$F = .0003T - .03\sqrt{T}$	$F = .0003T + .03\sqrt{T}$
O	62,000	$F = .00008T - .02\sqrt{T}$	$F = .00008T + .02\sqrt{T}$
P	380,000	$F = .00002T - .009\sqrt{T}$	$F = .00002T + .009\sqrt{T}$
Q	840,000	$F = .000005T - .004\sqrt{T}$	$F = .000005T + .004\sqrt{T}$

The control limits in Table 9 were computed in the following manner:

Problem: Derive an equation for computing the minimum number of failures, F, that can be expected during a total of T test hours if, at a 98% level of probability, the average reliability of all lots tested is estimated to be equal to the O level.

Given: N = Total Sample Tested
t = Length of Test
T = Total Test Hours
F = Maximum Number of Failures in Test Time T

Solution: Let $\bar{p}$ = the average fraction failures at Level O.

Then, at the 98% probability level, $\bar{p} = p_1 - 2\sqrt{p_1 \times (1 - p_1)/N}$

And, since $\bar{p} = F/N$ and $N = T/t$

$$F = p_1 T/t - 2\sqrt{p_1(1 - p_1)T/t}$$
Substituting $p_1 = .0195$ and $t = 250$

$$F = .0195T/250 - 2\sqrt{.0195 \times .9805 \times T/250}$$
$$= .000078T - .0175\sqrt{T}$$

Note: This equation appears in the revised version of MIL-C-25 Table 9. as $F = .00008T - .02\sqrt{T}$

Problem: Compute the minimum number of test hours that must be accumulated in order to determine whether a product qualifies for the O Level of reliability.

Solution: T is minimum when F = 0.

Substituting 0 for F in the equation, $F = .00008T - .02\sqrt{T}$,

$$0 = .00008T - .02\sqrt{T}$$
And T = 62,500 hours

Note: This value for T is shown in Table 9 of the revised version of MIL-C-25 as 62,000 hours.

Problem: Derive an equation for computing the maximum number of failures, $\bar{F}$, that can be expected during a total of T test hours if, at a 2% level of probability, the average reliability of all lots tested is estimated to be equal to the O Level.

Solution: Let $\bar{p}$ = the average fraction failures at Level O.

Then at the 2% probability level, $\bar{p} = p_1 + 2\sqrt{p_1(1 - p_1)/N}$

And, since $\bar{p} = F/N$ and $N = T/t$
$$F = p_1 T/t + 2\sqrt{p_1(1 - p_1)T/t}$$
Substituting $p_1 = .0195$ and $T = 250$
$$F = .00008 T + .02\sqrt{T}$$

Note: This equation appears in the revised version of MIL-C-25 as the qualification revocation equation.

CONCLUSIONS

The multilevel reliability requirement offers a practical approach to the problem of incorporating reliability assurance provisions into part specifications. A specification embodying such a requirement does not require periodic updating as the state of the art advances inasmuch as requirements pertaining to higher levels of performance are included in the specification and can be applied as soon as these higher levels are attained. Such flexibility is desirable both to the manufacturer and to the user of a part. The former can obtain recognition for significant improvement in the performance of his product, while the latter can determine without additional testing whether parts are being manufactured that have the performance characteristics he desires.

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EFFECTIVE QC INCREASES POLARIS RELIABILITY

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Much publicity has been given to the Polaris program in many fields. Without doubt much of this is deserved since the Polaris not only represents the first operational inertially guided missile, but, what may be more important, the accumulation into one deterrent weapon of the latest technological advancements in many fields including navigation, sonar, communication, ship building, propulsion, etc. Yet despite the size of the task, it was accomplished successfully on a crash basis in record time.

In order to cope with the speed of the program, quality control methods had to be devised that were simple and quick on the feedback. This paper will describe two methods, one used in inspection and another used in test, that proved highly successful in controlling the workmanship and reliability of this fast moving project. They are described not because they are brilliant new approaches nor because they are panaceas, but rather because of their simplicity and adaptability to any program.

The first of these two, a method for controlling workmanship during assembly came about through the need for identification of operators who required more training. The program represented a new standard of workmanship and required more careful work because of the compactness of the components and also the use of semi-conductors. To make matters more difficult there were in the guidance and fire control systems numerous types of units and low production quantities. This resulted in a very heterogeneous group of assembly operators. The problem was to obtain a quality report that would sum up this type of operation in terms of quality or workmanship.

The common elements in all of the work performed were soldering, crimping, dirty joints, missing parts, etc. (See Figure 1 for typical code list.) Therefore, we set about to list weekly the number of defects reported by the inspectors for each operator. In addition, like defects were totalled and a weekly report was issued of the most prevalent defects in the assembly area by foreman. Figure 2 shows a typical weekly report indicating operator check numbers and defect types. It will be noted that not every operator delivered work to inspection each week and that conversely if they did and no defects were found this was recorded by a zero. In this manner each week a ratio of the total number of defects in the area to the number of operators turning in completed work could give a figure for an average number of defects per operator. A plot of this ratio is shown in Figure 3 showing the dramatic results achieved during the first six months of its inception. Although this measure may seem arbitrary, through usage and its own simplicity it has been a very good yardstick.

In the implementation of this plan, however, the work of the different operators cannot be absolutely compared since one may work on a harness consisting of several hundred connections while another may work on a chassis consisting of many fewer connections to delicate semi-conductor elements packed together very closely. Also, there may be several new operators in a particular area making it unlikely that the foreman will appreciate being compared to other foremen. One thing, however, that can be insisted upon and on which much of the success of the plan depends is that each manufacturing foreman use the reports to improve the performance of those operators that have the greatest number of defects and if necessary transfer them to a more suitable job if they cannot attain an acceptable level of workmanship. At the beginning of the program, especially, three characteristics were necessary in an operator to be successful: accuracy, speed and versatility. The first two are obvious, the third may require a word of explanation. Many changes were introduced in rapid succession and very few operators worked on the assembly of only one type of unit, some of which took many days to assemble. It was, therefore, very important that operators with the proper temperament be selected for the project.

By the end of the first quarter of 1960, it was obvious that a plateau had been reached and something had to be done to further reduce the number of defects per operator. It was decided to have periodic meetings between assembly and quality control foremen to discuss ways of reducing defects further. Several worthwhile corrections

in the process resulted.

For example, damaged parts in assembly were excessive. Through discussion at the meetings, it was learned that the major cause of this defect was the fragility of transistor leads. A handling program for these parts was instituted throughout the whole plant with gratifying results. However, it was not until someone suggested building up the base of the transistor with some type of epoxy to move the flexing point of the leads beyond what was believed to be a length of the leads partially oxidized in the vendor's operations that the problem was solved. Addition of this step in the vendor operations virtually eliminated any lead breakage problems in our plant.

In another case, differences between the operators and the inspectors as to the amount of solder on a joint were thought to be the reason why so many connections were called because of "insufficient solder". To our surprise the answer turned out to be the inadequate thickness of the gold plate on the connector terminals and the result- ant corrosion. This prevented solder flow and adherence of the solder. As a result, negotiations with the vendor cleared up the problem and today it is virtually non- existent.

Yet, despite such progress the defects per operator were not coming down. Apparently we were not getting to the operators. Near the end of the year an inten- sive program was started in this direction. This time all the operators and the inspectors were given directions on the correct methods of performing those three or four operations that in past weeks accounted for the majority of the defects. The weekly bar chart shown in Figure 4 illustrates how the topics were selected. The discussion between operators and inspectors at these meetings proved stimulating and worthwhile. Immediate improvement in workmanship was noted the following week by a downward trend in the curve and in January of this year the lowest number of defects per operator as of that date was reached. We had cut defects to one sixth in a year and a half!

To further impress the operators with the need for good workmanship, posters are placed in the work area relating to the major points covered at the last meeting. In this manner it becomes more than a one hour discussion and impresses the ideas daily on the minds of each operator. A colored chart is also posted in each foreman's area listing all his operators and relating their performance each week to a color code. A quick glance at the chart will reveal through the color pattern whether the fore- man's area is within the goals set, whether he is beginning to be in trouble or is already completely out of control. It might be added that at any time the foreman can request daily feedback for their areas and the tabulations can be made available by the next day.

The second method improved reliability in a more intangible way through a con- siderable reduction in trial and error troubleshooting during test. This method, called a test plot, shows the hourly progress during a particular test on a single unit.

Figure 5 shows a typical test plot and demonstrates the upward trend of good time during which the test is progressing according to the test procedures. The downward trend of the curve represents bad time during which additional unexpected problems are being located and resolved. The code numbers under the bad time identify the probable nature of the problem. The horizontal lines indicate delays due to rework, changes, shortages, etc., not directly under the test area jurisdiction. Since this chart is kept hourly by the tester it can be seen at a glance without disturbing any- one what the progress of the particular unit happens to be through the test. Reading the code underneath the chart indicates the nature of the problem and identifies the type of support assistance that may be necessary if too long a delay is observed. If the downward trend extends for more than a few hours the foreman can immediately re- view the situation and call in additional help before too many hours are wasted. This procedure has expedited many tests since often the test equipment or design engineers understood the limitations of the circuitry better than the testman and were also aware of design changes that may not yet have been integrated in the test equipment or the procedures due to the rapidly moving program. In a short test of a few hours dur- ation this technique of test plot would not prove very useful, however, it should be remembered that these tests of which we are speaking were in some case a few hundred hours in duration and, therefore, some indication of the progress was necessary to accumulate and summarize the total test picture of the unit.

The code assigned to the bad time has nine separate categories. Briefly, they are workmanship errors, engineering design problems, fabrication problems, test equipment problems, selling problems, engineering changes, component failures, test procedure problems and test personnel problems. Through this identification of the problems corrective action can be initiated very quickly at any particular time for a given unit in test and through casual perusal of the test plot recurrent failures of a particular category can be identified for their effect on the program. For example, the effectiveness of the complex universal test equipment used to test the fire control units could be evaluated from the amount of bad time necessary to correct test equipment problems.

The usefulness of these test plots was not limited to the very short, almost instantaneous, feedback time on the factory floor. The test plots are equally useful in predicting schedules by reviewing trends from the previous tests and also for quoting. In both cases the decisions can be substantiated by reference to the test plots and improvement factors can be included based on projections of the learning curve. The learning curve for the first ten systems is shown in Figure 6. It has a very rapid decrease in test time to the end of the third fire control system. We like to attribute some of this increase in productivity to the test plot method and its quick reaction time.

It might be interesting to note that this method is of very little use in the test area today since all but three units require less than 10 hours test time. The remaining three total about 150 hours to complete test. Even so, the problems are mostly of a component nature and require very little support experience.

The simplicity and the effectiveness of these two techniques lie in the fact that all of the records are made on the spot in test and inspection at the time when the information is most familiar to the people who are actually doing the work; no elaborate mathematics or analyses are necessary. The cycle time for the use of the data is no more than one day in the case of the workmanship reports and a matter of instantaneous usage in the case of the test plots. Both reports not only furnish immediate information that can be applied to nearly every program but they also are useful at higher managerial levels to observe overall aspects of operations.

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005 INSULATION DAMAGED – MECH	153 DEFECTIVE LACING
132 EXCESS SOLDER	154 DAMAGED FINISH
133 INSUFFICIENT SOLDER	157 STALKING
137 BURNED WIRE	163 INSUFFICIENT SOLDER FLOW
138 POOR CRIMPING	221 DEFECTIVE WELD OR SOLDER
144 MISSING PART	230 DIRTY
147 INSULATION BACK TOO FAR	340 INSTALLED IMPROPERLY – WIRING
149 DIRTY SOLDER JOINTS	731 AUTOMATIC CONTINUITY CHECKER
151 FOREIGN MATERIALS	750 MISSING COMP HARDWARE OR RUN
152 BROKEN WIRES	848 WRONG PART – ELECT VALUE

Figure 1

TYPICAL OPERATOR DEFECT SUMMARY

OPER. NO.	51	52	53	1	2	3	4	5	OPER. NO.	51	52	53	1	2	3	4	5
1137	5		2	6	6	18			4447	7	5	5	4	0	0		
2012		0	2		3	2			4604	3	17	4	3	1	5		
2925	3	0	0	1	3	0			4517			0	1	0	0		
2942	10	23	6	10	6	14			4571	0		0		0	0		
2956	1	0	0	0	0	0			4652	9	23	8		2			
4012	8	5	6	3		2			4695		0	2		1			
4195	5	12	19	15	8	14			5047	3		0		0			
4339	2	10	12	20	11	3			5079		31		8		0		
4380	3	3	2		1	4			5232	1	1	5	4	1	3		
4431	9	14	12	29	10	16			5875	3	9	3	3	2	5		

Figure 2

AVERAGE WEEKLY NUMBER OF
DEFECTS PER OPERATOR
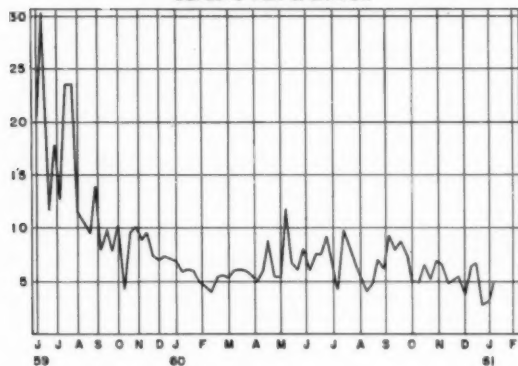
Figure 3

DEFECT DISTRIBUTION FOR WEEK 27

Figure 4

TYPICAL TEST PLOT

Figure 5

LEARNING CURVE ON FIRE CONTROL TEST
OPERATIONS
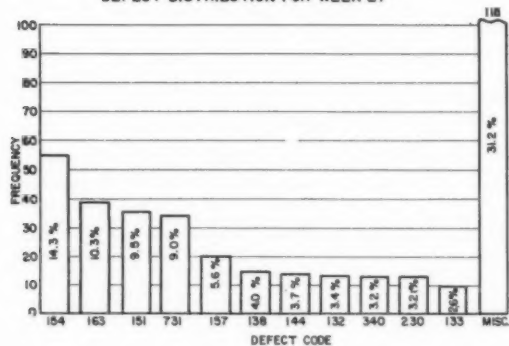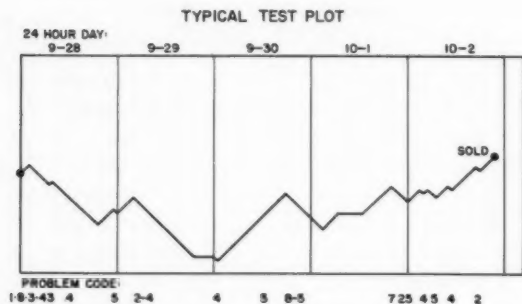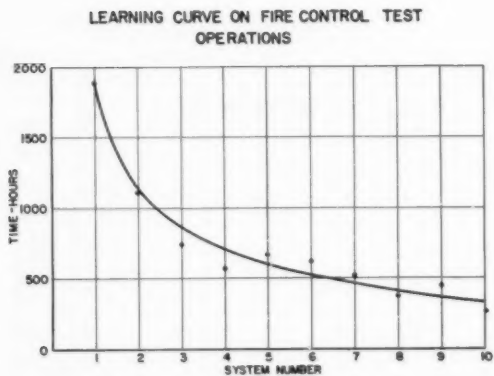
Figure 6

QUALITY CONTROL AND RELIABILITY ORGANIZATION
A PROFESSIONAL APPROACH *

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ABSTRACT

This paper attempts to provide an insight into the problem of se-
lecting an organizational structure to provide professional level qual-
ity control and reliability activities for the industrial unit. Con-
sideration is given to organization as a function of corporate structure,
size of manufacturing unit, nature of products, and nature of markets.

INTRODUCTION

Historically, the manufacturing establishment had a going inspec-
tion department as its principal quality control function. With this lim-
ited scope of interest there were few problems of organization, if any.
A necessary service for the plant manager or factory superintendent was
being performed. However, with the advent of the application of statis-
tical principles, first in support of the inspection function, then to
facilitate in-process control, and now to provide valid reliability fac-
tors, the matter becomes increasingly complex. Dr. Romig summed it nice-
ly in his 1953 Shewhart Medalist address, when he said:

"The principles of statistical quality control embody the
applications of the scientific method to all phases of our indus-
trial life including management, research and development, pur-
chasing and vendor relations, plant evaluations, production en-
gineering, inspection, test, accounting and industrial relations.
It takes certain of the operations research techniques used by
the military and develops scientific teams that are considered
by many managements as their most valuable adjuncts." [1]

If these words may be regarded as a charge, it is easy to see why the
task of organizing to fulfill the implied mission is indeed a formida-
ble one. And, it may be added, is seldom completely consummated.

It is the purpose of this paper to give the reader an increased
awareness of the need for a sound professional approach to the matter
of quality control and reliability organization. In the sequel, typical
management dilemna arising in this connection will be discussed. And,
the importance of human relations will be stressed. It is well known to
all quality control practitioners that the problems generated by the
human relations factors not only affect the degree of success, but may
also shape the organizational structure of the quality control and reli-
ability functions. Throughout the discussion, the writer subscribes to
the opinion that quality control and reliability are inseparable func-
tions, and both should be under the ultimate control of one group.

ATTACKING THE PROBLEM

Now, let us consider ways in which one may attack the problem of
creating an organization.

From the beginning, it is necessary to have a clear definition from
top management of its policies, objectives, and degree of financial
support that will be forthcoming. The odds are against a successful
build-up of a professionally competent quality control and reliability
organization without such a foundation. If it is not readily obvious
why this is the case, a quotation from Feigenbaum, and subsequent con-
sideration of its implications, may facilitate an appreciation of this
need. In discussing the nature of an effective quality control organ-
ization, Dr. Feigenbaum says,

* LCS Code 300:10:000

"It is a device whereby management delegates authority and responsibility for product quality, thus relieving itself of unnecessary detail and permitting the benefits of specialization, yet retaining for itself the means for assuring that quality results will be satisfactory, in terms of top management's standards and policies."
(2)

We may note that the quality control organization is the seat of management-delegated authority and responsibility for product quality. For this to be so in fact, and to enable the quality control and reliability group to discharge effectively its responsibilities, the organizational structure must give to part of the group at least minimal line authority. Responsibility and authority are the veins and the arteries of any function within the corporate body. Just as the heart cannot perform its function without veins and arteries, neither can the quality control group. Authority commensurate with the responsibility must be enjoyed, or the quality and reliability responsibilities cannot be fulfilled successfully. At this stage in our discussion, it may be well to take cognizance of some of the more important responsibilities, since they are a guide to the organizational structure, and to the kind of talents needed in the group. Once again, the writer will draw upon Feigenbaum. He lists the following as among the more important responsibilities.

"1.   To aid management in the preparation, adoption, and continued evaluation of a factory-wide program of quality control, expressed in terms of written company policy.

2.   To advise line, staff, and functional groups in manufacturing and Engineering as far as their quality control activities are concerned.

3.   To develop and to maintain for top management an effective product-quality appraisal system.

4.   To stimulate quality research.

5.   To maintain or to stimulate quality-control education.

6.   To aid management in stimulating a quality-minded attitude throughout the plant.

7.   To assist - and, in some cases, to act for- management in the actual details of administering and coordinating the factory-wide quality-control program.

8.   To establish and to perform certain quality-control services.

9.   To advise management in the product-quality aspects of the establishment of new plants and manufacturing areas.

10.   To aid Marketing and Sales in its merchandising and product-planning activities and in product advertising campaigns.

11.   To develop a competent and efficient group of men and women to carry on the quality-control staff functions." (3)

To these should be added an additional responsibilty or two:

12.   To put "statistical" in front of "quality-control" whenever appropriate.

13.   To generate a plant-wide reputation for fair, unbiased solutions to its problems.

14.   To keep up to date in the pertinent applications of statistics and mathematics.

These fourteen do not comprise the full set of responsibilities a quality control group may be given. They do, however, serve the purpose of providing a framework within which to operate while considering the type of organization needed, and the type of personnel required.

As Feigenbaum also points out, all of these responsibilities become functions of a small number of general issues:

1)   How is quality control related to the inspection function?
2)   Should the quality control staff have any direct product-quality responsibilities?
3)   How is the staff to be organized?

4) What is the status of the staff and its manager or director?

Resolution of these issues, and assignment of the responsibilities will be discussed in the next section, where various forms of organization are considered. As various possible structures are being explored, the reader should constantly remind himself that quality contains U, the precious ingredient without which there can be no quality, no reliability, no group effort. But the U must be both singular and plural, or else it vanishes literally and figuratively. Accordingly, a useful, workable organization must recognize the community of interest, and provide formal or informal means for coordination all pertinent interests.

Now, what interests may be recognized as relevant? A clue may be obtained to a first approximation to the answer by a brief examination of the Quality Control Wheel, Illustration 1.

THE QUALITY CONTROL WHEEL

Illustration 1

(4)

While a more complete discussion of this concept may be found elsewhere, a cursory treatment is germaine to the present purpose. It can be seen quite readily that the quality control function is a focal point. Through the formal and informal organizational lines of communication, there must be rapport between quality control and sales, between quality control and manufacturing, between quality control and design, and among sales, design, and manufacturing.

The quality control function at the hub of the Wheel should consist of three main elements, after Juran, as discussed by Scott. [5] These elements are Inspection, Statistical Quality Control, and Quality Assurance.

The first is concerned mainly with the manufacturing part of the Wheel, since it deals with receiving inspection, process inspection, finished goods inspection, gage maintenance, test equipment maintenance, salvage, day-to-day trouble shooting, etc. These activities may be termed the acceptance function.

Statistical quality control, the prevention function, includes statistical methods, training in quality control, analysis of data, process capability studies, economic studies, design of sampling plans, and

design of experiments. It deals mainly with the manufacturing and the
design functions.

The third, quality assurance, covers customer complaints, quality
audit, check inspection, market quality determination, accuracy of in-
spectors and inspection methods, executive reports on quality, quality
certification, reliability activities, and responsibility for valid spec-
ifications which have been subscribed to by all parties concerned. This
function, therefore, is largely tied in with sales, but still must work
with manufacturing and design.

At this point, the reader should be ready to consider a few of the
most likely organizations.

SOME ALTERNATE ORGANIZATIONS

In this section, several different organizational structures will be
considered. Their merits and disadvantages will be discussed to a limited
extent, with the hope that the interested reader may be provided some
guidance in coping with his own organizational needs. The keynote for the
(6)
discussion to follow can be taken from a few remarks of Charles A. Bicking:

> "The organization should follow the sound principle that who-
> ever is responsible for achieving proper quality in manufacture
> should not also be responsible for what constitutes proper
> quality against which the achieved level will be judged.
>
> The exact organizational chart is not important and may vary
> from company to company. There must be a clear separation,
> however, of the function of manufacturing quality into the
> product and the function of prescribing the quality standards
> and assessing the degree of success achieved in meeting the
> standards."

A.   A Completely Decentralized Or Single Unit Establishment

We may begin with the simplest case, and build upon this, until we
have developed as complex a case as may be suitable for the present
paper. In this, and the following, section(s), the thinking and writings
of several students of the subject, in addition to the writer, will be
synthesized. Rather than attempt to give specific reference each time,
the sources drawn upon in varying degrees will be cited in the references
below.

Obviously, where there is only one physical plant, be it a complete-
ly decentralized plant of a multi-plant company, or a single unit estab-
lishment, the same considerations obtain. Illustration 2 indicates one
possible organization for this case.

General Manager

Sales   Design   Manufacturing   Finance

Line Superintendents   QC and Reliability
                                        SQC Procedures
                                        Inspection
                                        Quality Assurance
                                        Reliability
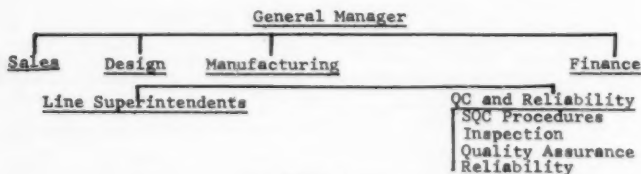
Case A
Illustration 2

Only the area of immediate interest, quality control and reliability, is
elaborated upon. In this, and in the illustrations to follow, listings
which appear to be functional rather than titular do not necessarily im-
ply separate personnel. Indeed, several activities may be performed by
one individual.

Case A is an organization of the sort that may have evolved, or "just growed". The nature of the chief inspector's job probably changed as a function of competitive pressures and/or a growing awareness of the changing character of the quality control function. He is now the quality control supervisor or manager, reporting to the manager of manufacturing or plant manager. The dotted line represents a communication line (as it also will in subsequent illustrations) which must exist, or the preventive function will not be operative.

If, now, we recall the keynote of this section, it is readily recognized that this form of organization violates the principle set forth, with regard to the separation of functions of achieving the specific quality, and measuring the degree of achievement. Applied statisticians are quite familiar with the term, bias. We use random sampling, laboratory controls, blind samples, etc. to eliminate or minimize it. Would it not, then, be anamolous to countenance an organization conducive to bias, while we disclaim it in our estimation of process parameters or in analytical results?

An organization such as that presently under discussion has an inherent bias. If a group sets standards by which to appraise its own efforts, it would be quite natural for the standards to be applied and interpreted in such a way as to put the manufacturing quality control in a somewhat more favorable light than may actually be the case. This may be called, to coin an expression, proprietary bias, or the bias due to defending one's own work. There is no real quality conscience in this set-up. And, the void can only be filled by a clear separation of functions, as recommended above. To accomplish this, the organization depicted as Case A need only be modified somewhat to result in Case B 1, as in Illustration 3.
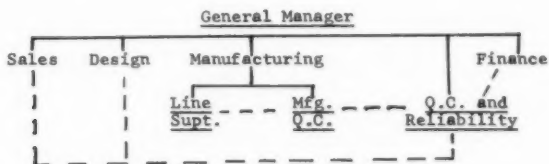
Case B 1

Illustration 3

There is now a conscience. The manufacturing quality control group has the responsibility (and, it is to be hoped, sufficient authority) for in-process and final product quality control, including inspection, and for recommending materials and processing changes in the interests of maintaining or improving quality. On the other hand, the staff group has the responsibility for setting the standards against which the product is evaluated, and serving as the management agent. Their responsibilities include, as a partial listing only, specifications, quality control procedures and standards, auditing the manufacturing quality control results, keeping management informed, making reliability studies, and acting as liaison between sales, finance, and design on the one hand, and manufacturing on the other. It should be obvious to the reader that both groups are needed to fulfill the mission as indicated above, in terms of the 14 responsibilities which were enumerated earlier. Since the special skills necessary to implement the manufacturing quality control function are seldom present in the same personnel who possess the special skills requisite for the staff quality control function, the groups can rarely be combined with success. Incidentally, this is another reason why the organization in Case A can seldom be truly effective to a high degree in terms of quality control and reliability.

A variant of the same basic organization, and one which in many
situations would be more effective, is presented in Case B 2, Illustration
4, without further discussion.

General Manager

Sales   Manufacturing   Technical   Finance

Line   Mfg.   Res. and Staff Eng.
Supt   Q.C.   Dev.   Q.C.
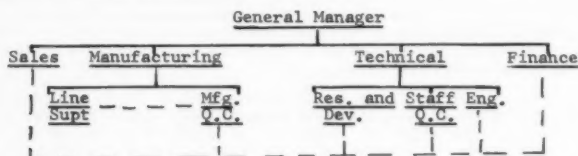
Case B 2

Illustration 4

B.   A Multi-divisional Establishment, With Centralized Policy Making

In a multi-divisional or multi-plant situation, a somewhat different
organization is ordinarily required. However, there may be such complete
decentralization and autonomy that each plant or division may establish
its own policies independently of over-riding corporate policies. In
this event, Case B 1 or B 2 should adequately provide for a meaningful
quality control and reliability organization. But, more often than not,
there will be corporate policies which provide the context and restric-
tions for divisional activity. When this is the case, the optimum organ-
ization for quality control and reliability is one which, when viewed
superficially, appears quite complex. However, the very characteristics
which create the impression of complexity can give it real strength.

At the corporate staff level there should be a group who, by their
experience, training, and capabilities can be truly regarded as profes-
sional in the fields of quality control, reliability, and applied indus-
trial statistics. This group, acting as the agent of the top management
of the company, establishes policies, provides consultation to the plant
or divisional staff quality control and reliability groups, and audits
the pertinent activity of each plant or division. There must be a direct
line of communication between this corporate staff group and each local
staff quality control and reliability group. And, this top level staff
group must act as the quality conscience for each of the plants or div-
isions, and the entire company as well.

Before leaving this section, the author wishes to point out that
only two or three situations have been discussed, and to a rather limited
extent at that. But, a full treatment of the subject cannot be rendered
in anything as short as a paper of this nature and for this purpose.

CONCLUSION

Rather than attempt a summary of the foregoing discussion, since
the subject was so briefly touched upon, we will mention a few of the
corporate ramifications that have a bearing on the present subject. Any
architect of a quality control and reliability organization must take
these into account if he is to build an enduring edifice.

Some consideration has already been given to the corporate structure,
in terms of decentralized versus centralized control. Size of the manufac-
turing unit, in personnel and sales volume, must also be considered. A
small unit, under the close personal control of the general manager, can
not tolerate the comparatively more complex organization required to fill
the need in a unit where the demands on the general manager preclude his
close personal control.

Further, the nature of the products have a bearing on the most appropriate form of organization. For example, in the electronics, armaments, and missile industries, the entire quality control organization must be pointed towards reliability. On the other hand, a producer of bulk materials must have his quality control organization oriented towards quality assurance.

Another factor which may influence the quality control and reliability organization is the importance of government contracts in the market of the company. Also included in the nature of the market is the extent to which the products are end use items, or are by way of being producers' goods, which are raw materials to the customer. Consequently, varying proportions of terminal product and non-terminal product, from one company to another, also have considerable influence on the nature and place of the group charged with the quality responsibility.

No matter what the organizational structure may be, or at what levels the quality control responsibilities and authorities are placed, certain cautions are pertinent.

Such a group must be flexible, somewhat informal, and in possession of appropriate talents and skills. Not the least of these is an ability to satisfy simultaneously the conflicting demands which frequently arise, such as between sales and manufacturing, or design and manufacturing. Further, the precepts of sound organization, such as the awareness of the limits of the span of control that any one executive can exercise effectively, and cognizance of the need for a proper balance between line and staff functions, must be followed.

The ultimate test of a sound quality control and reliability organization is, does it make it possible to accomplish its mission? Therefore, it should be designed with the mission in mind. A professional approach to creating the organization must start with a clear understanding of management's concept of the mission, and must consider the inter-relationships that will be present between quality control and reliability activities on the one hand, and all other functions of the plant or division, on the other.

FOOTNOTES AND REFERENCES

(1) Harry G. Romig, "The Role of Quality Control in Industry," INDUSTRIAL QUALITY CONTROL, July, 1954, Vol. XI, No. 1, page 18.

(2) A.V. Feigenbaum, QUALITY CONTROL PRINCIPLES, PRACTICE, AND ADMINISTRATION, McGraw Hill Book Company, Inc, New York, 1951: page 44.

(3) Ibid. See pages 46-47.

(4) S.P. Zobel, "Quality Control from Front Door to Back Door," INDUSTRIAL QUALITY CONTROL, December, 1960, Vol. XVII, No. 6.

(5) C.R. Scott, Jr., "Organizing For Quality," QUALITY CONTROL HANDBOOK, J.M. Juran, editor, McGraw Hill Book Company, Inc., New York, 1951

(6) Charles A. Bicking, "Managing Quality for Maximum Profits," TOOLING AND PRODUCTION MAGAZINE, January, 1960.

(7) Chester I. Barnard, THE FUNCTIONS OF THE EXECUTIVE, Harvard University Press, Cambridge, Mass., 1948.

(8) A general reference is herewith made to the many helpful papers in INDUSTRIAL QUALITY CONTROL, which were read for background. They are too numerous to cite for the present purpose.

AN ADAPTATION OF THE
MIL-STD-105B PLANS TO RELIABILITY
AND LIFE TESTING APPLICATIONS*

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SUMMARY

This paper presents a procedure, together with tables of necessary conversion ratios, for applying the MIL-STD-105B sampling-inspection plans to reliability and life-testing applications. The method assumes the Weibull distribution (including the exponential distribution) as a statistical model for item lifelength. Inspection of sample items is by attributes with life testing truncated at the end of some specified time, t. Lot quality is evaluated in terms of mean item life, μ. Both t and μ are measured from some reference time, γ.

INTRODUCTION

This paper represents an extension of a paper and set of sampling plans for reliability presented by the authors at the Seventh National Symposium on Reliability and Quality Control[1]. Both these papers are generalizations of papers by Sobel and Tischendorf[2] and by Epstein[3] that appeared respectively in the Proceedings of the Fifth and the Sixth National Symposium and by Altman[4] that appeared in Industrial Quality Control. Plans have also been prepared by Myers[5] and related work done by Gupta and Groll[6]. However, in this paper and the one to which it is related the Weibull form for the underlying life density is assumed whereas in the other papers cited the exponential model (or the gamma variable which is the sum of exponential variables) is assumed.

Numerous studies of lifelength for a variety of materials and components have shown the Weibull model to be an excellent one to use as an approximation to the true distribution of life. The exponential model, which has been commonly used up to this time, requires the assumption of a constant failure rate regardless of the life of the items while the assumption of a gamma distribution as the failure model has the characteristic that as items increase in age, the failure rate tends to a fixed value. These assumptions may in many cases be far from realistic, particularly when failure is of the wear-out type. It has been demonstrated that sampling inspection decisions based on the assumption of the exponential are highly distorted if the true underlying distribution of life-length is of the Weibull form.

The objective of this study is to present a working procedure, together with tables of necessary conversion ratios, for applying the MIL-STD-105B[7] sampling inspection plans to reliability and life-testing applications for which the Weibull model is appropriate. A table is also included for the special Weibull case ($\beta = 1$) for which the Weibull is the same as the exponential. Thus both possibilities for a statistical model for life-length are covered.

THE SAMPLING INSPECTION PROCEDURE

The following acceptance-sampling procedure has been adopted for the adaptation considered here of the MIL-STD-105B plans for life testing:

    (1) A random sample of n items is selected from the lot.

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(2) These sample items are tested for life over some preassigned test period t units in length.

(3) The number of test items that fail prior to time t is observed.

(4) If the number of items failing is equal to or less than some specified acceptance number, c, the lot is accepted; if the number that fails exceeds the acceptance number, the lot is rejected.

The sample sizes and acceptance numbers used in the above procedure will be those specified by the MIL-STD-105B tables. The procedure as outlined above is for single sampling; through simple and appropriate modification, the 105B double-sampling and multiple-sampling plans may be likewise employed. It may be noted that the acceptance procedure is the same as that specified for the MIL-STD-105B plans with the single exception of the use of a test truncation time, t, (and the application, of course, to life-testing data).

The probability of acceptance for a lot under the acceptance procedure outlined depends solely upon the probability, p', that an item will fail before the end of the test period, t. One may note from a study of the mathematics as outlined in the Appendix that if the test truncation time, t, is preassigned and if the value for β, the shape parameter, is known the probability, p', of failure is a function only of mean item life, μ. This fact makes it possible to use this attribute acceptance procedure to evaluate lots in terms of mean item life; the operating characteristics for any specified plan (in terms of c and n) depend only on t and μ.

In order to allow for any desired test-time truncation value, t, and thus provide plans for general use, the tables included with this paper have been prepared in terms of the dimensionless ratio, t/μ. Actually, to give more conveniently usable figures and to work in terms adopted for the 105B plans, the ratio is given in terms of percent (t/μ) x 100 is used. Each of the 105B plans is cataloged and described in terms of the (t/μ) x 100 ratio. These ratio values are used in the same way as the percent defective values are used in the selection and application of the 105B plans for ordinary attribute inspection. When applying the plans to a specific life-testing application, use of the ratio to convert from test time to lot mean (or vice versa) will be found quite easy. Examples of application will be given near the end of the paper.

It will be noted that it is necessary to assume a value for β, the Weibull shape parameter. For many applications this value may be known. Its magnitude may have been determined for the product in question from past life-length research data, from the results of past inspection data, or from some other source. If the value for β is not known, procedures are available for estimating this parameter (and the γ location parameter if this, too, is necessary)[8][9].

<center>THE TABLES OF RATIOS FOR THE 105B PLANS</center>

Tables of ratios for adapting the 105B plans to reliability and life-testing application have been prepared for each of seven values for β, the Weibull shape parameter. These seven values range from 1/2 to 3-1/3, covering the span commonly encountered with industrial products. A table for $\beta = 1$, which is the exponential case, is also included. These tables will be found at the end of this paper as Tables 1-A through 1-G.

Each table lists for each 105B Acceptable Quality Level (AQL) value the corresponding (t/μ) x 100 ratio. These matched ratios will be found in the column headings under each of the respective 105B Acceptable Quality Level values (which are in terms of 100 p' %, the acceptable percent defective). Each ratio value gives for all 105B plans of the corresponding AQL, a measure of lot quality for which the producer's risk or probability of rejection will be low. This risk of rejection will be the same as that encountered in the normal use of the 105B plans for attribute inspection. It will be recalled that this risk is not a constant value of, say .05, as in most previous tables of acceptance inspection plans, but ranges from as low as 0.01 to as high as 0.20. The risk varies with the size of the sample, which in turn varies with the size of the lot. For large lot sizes (and thus large sample sizes) the risk is relatively small; for small lot sizes it is relatively large. The specific risk value for any plan of interest may be obtained from the corresponding operating characteristic curve which will be found included with the 105B tables.

The interpretation of these matched Acceptable Quality Level ratios for life-testing and reliability use may be demonstrated by means of a specific case. Assume, for example, that $\beta = 1-2/3$ and that a 105B plan with an AQL of 4.0% is to be used. From the table of ratios for $\beta = 1-2/3$, which is Table 1-E of those included at the end of this report, it will be found that the corresponding t/μ ratio value at the AQL is 16.42. Thus lots for which $(t/\mu) \times 100 = 16.42$ are "acceptable" and the probability of acceptance will be high (the probability of rejection low). If the test period, t, is, say, 1000 hours, $(100/\mu) \times 100 = 16.42$ or $\mu = 6,090$ hours; the mean life for the items in the lot must be 6,090 hours for it to meet the 105B acceptable quality level standards.

In the body of each table of conversion ratios will be found, for each 105B plan, ratios for which the probability of acceptance is .10. These correspond to lot tolerance percent defective (LTPD) figures which furnish a useful measure of consumer's protection. They represent unsatisfactory lot quality values and ones for which the probability of acceptance is low. Unlike the risks associated with the AQL which vary with sample size, the risk at the LTPD quality used for the tables presented here is at .10 for all plans.

For the example cited above in which the AQL is 4.0%, suppose the Sample Size Code Letter is L. Reference to the table of conversion ratios for $\beta = 1-2/3$ shows the LTPD ratio to be 31. With the test period, t, designated as 1000 hours, the value for μ, the lot mean life may be readily determined. Substitution gives $(1000/\mu) \times 100 = 31$ or $\mu = 3,220$ hours. Thus lots whose mean life is 3220 hours or less have a probability of at most .10 of acceptance.

With the use of these complete tables of conversion ratios (tables 1-A through 1-G), suitable 105B plans may be selected in terms of either an AQL or the LTPD. If, instead, some 105B plan has been specified, its operating characteristics can be evaluated. Examples of such use will be outlined in the material that follows.

As a supplement to these tables, Table 2 has been prepared. This table gives the $(t/\mu) \times 100$ ratio at the Acceptable Quality Level for an additional number of values for β, the Weibull shape parameter. Ratios at the AQL for the β values used in Table 1 are also included. As the Acceptable Quality Level supplies the operating characteristic of most interest in the application of 105B plans, the ratio values in this table may be all that are necessary for many applications.

Example (1)

For a simple example of application, consider a receiving inspection case for which incoming lots of a product are to be tested for lifelength by sampling. From past experience with the product it has been determined that the life distribution can be expected to follow the Weibull form with a value for β, the shape parameter, of approximately 1-1/3. The value for γ, the location parameter, is expected to be 0. The MIL-STD-105B plans are to be employed. A test period for the sample items of 200 hours and an Acceptable Quality Level in terms of percent defective (as used in the Standard) of 1.5% have been more or less arbitrarily selected for use. The size of incoming lots is 5,000 items. Inspection Level II, the one for normal use, will seemingly be appropriate. Single sampling is to be employed. The acceptance procedure for the above conditions and the resulting operating characteristics must be determined.

Reference to Table III of MIL-STD-105B shows that for a lot size of 5,000 items and for Inspection Level II, Sample Size Code Letter M is designated for ordinary inspection. Reference is next to Table IV-A of the Standard, the master table for normal single-sampling inspection. Here it will be found that for Sample Size Code Letter M and for an Acceptable Quality Level of 1.5% the sample size is 225 items, the acceptance number 8 items, and the rejection number 9. The acceptance-rejection procedure will thus be the following: (a) draw at random from the submitted lot a sample of 225 items and place them on life test for 200 hours, (b) determine the number of items that have failed by the end of this test period, (c) if the number failing is 8 or less, accept the lot. If the number is 9 or more, reject it.

The operating characteristics of this plan can be determined from information included in the Tables of $(t/\mu) \times 100$ Ratios included as part of this report. For this example reference will be to Table 1-D, the table of ratios for $\beta = 1-1/3$.

Examination of the two lines of Acceptable Quality Level values across the top of this table shows that for an Acceptable Quality Level in terms of p' (%) of 1.5, the Acceptable Quality Level in terms of $(t/\mu) \times 100$ is 4.69. With this latter ratio, and with the value for t, the test period length of 200 hours, the value for μ, the mean item life for the lot, can be determined. Thus:

$$(t/\mu) \times 100 = 4.69 \qquad (AQL)$$

$$(200/\mu) \times 100 = 4.69$$

$$\mu = 4,260 \text{ hours.}$$

One now knows that the operation of the plan is such that if the mean item life for the lot is 4,260 hours or more the probability that it will be accepted is high. (A rough value for this probability may be found from the operating characteristic curves in the Military Standard. For an AQL of 1.5 and for Code Letter M one may note the probability is approximately .97.) The Acceptable Quality Level is thus 4,260 hours.

The ability of the plan to protect the consumer may be measured by the lot mean life for which the probability of acceptance is low. The tables of $(t/\mu) \times 100$ ratios included in this report include ratios at the Lot Tolerance Percent Defective (LTPD) quality level, the level at which the probability of acceptance is .10. These ratios will be found in the body of the tables. Reference to the same table, Table 1-D for $\beta = 1\text{-}1/3$, gives an LTPD ratio of 13 for Sample Size Code Letter M and an AQL of 1.5. Computations similar to those previously made give:

$$(t/\mu) \times 100 = 13 \qquad (LTPD)$$

$$(200/\mu) \times 100 = 13$$

$$\mu = 1,540 \text{ hours.}$$

One now knows if the mean life for the items in the submitted lot is 1,540 hours or less, the probability of it being accepted is at most .10; the probability of its rejection is at least .90.

The operating characteristics in hours as computed above apply also (with the same values) if a double-sampling or a multiple-sampling plan for the same Sample Size Code Letter and AQL value is employed instead of single-sampling plan. For double-sampling in this application, the data for the plan will be found in Table IV-B of the Military Standard. The first sample size will be 150 items. These sample items would be tested for 200 hours. If 5 or fewer items failed within this time, the lot would be accepted; if 14 or more failed, it would be rejected. If from 6 to 13 failed, a second sample of 300 items would be selected and tested for 200 hours. If the total number failing (in the first and second samples combined) is 13 or less, the lot would be accepted, if it is 14 or more, the lot would be rejected.

Example (2)

For a second example, consider an acceptance-inspection by sampling application for which the following achievements are desired: (a) If the mean item life for the lot is 20,000 hours or more the probability of acceptance will be high. Lots of this mean life or greater are considered "acceptable." (b) If the mean item life for the lot is 6,000 hours or less, the probability of acceptance will be low - .10. A test period of 500 hours will be employed. It is expected that the item life distribution will be of the Weibull form with a value for β, the shape parameter of $3/4$. The value for the location parameter, γ, is zero.

The $(t/\mu) \times 100$ ratio at the AQL will be

$$(500/20,000) \times 100 \text{ or } 2.5.$$

The $(t/\mu) \times 100$ ratio at the LTPD will be

$$(500/6,000) \times 100 \text{ or } 8.3.$$

With these values, Table 1-B giving the (t/μ) x 100 ratios for $\beta = 3/4$ may be scanned to determine the appropriate MIL-STD-105B plan. One may note in this table that an AQL of 6.5 (in percent defective) corresponds to a (t/μ) x 100 ratio of 2.29. This is the closest value available for the desired ratio value of 2.5. The column under the 6.5 AQL value heading may next be scanned to find a close approximation to the desired value of 8.3 for the LTPD. A value, 8.2 is found corresponding to Sample Size Letter K.

Thus any MIL-STD-105B plan with Sample Size Code Letter K and for an Acceptable Quality Level of 6.5 will give approximately the desired operating characteristics for the specified test period of 500 hours. For single sampling, for example, the sample size will be 110 items and the acceptance number 12 as indicated in the MIL-STD-105B tables.

<u>Example (3)</u>

The procedure to be followed for cases in which the Weibull location parameter, γ, is not zero but is of some other known value may be illustrated by outlining a third example. The method to be followed in this case is to simply subtract the value for γ from the value for t, the test time to get t_o, and from μ to get μ_o. These transformed values t_o and μ_o are then used for all (t/μ) x 100 computations. The solution obtained in terms of t_o and μ_o can then be converted back to original values by simply adding the value for γ to each.

Consider, for example, an application for which a single-sampling plan with n equal to 35 and c equal to 1 has been specified. This corresponds to a plan with Sample Size Letter H and an AQL (in terms of p') of 1.5% in the 105B collection. Item life is measured in terms of cycles of operation. Protection against lots for which the average item life is less than 5,000 cycles is required. From experience with this product it has been determined that the Weibull distribution applies and that a value for γ of 2,000 cycles and a value for β of 2 can be expected. The problem is to determine a test time, t, in cycles that will enable the plan to meet the above requirement for consumer's protection. A related problem is to find whether the plan so determined will give adequate producer protection. It has been determined that a mean item life of 16,000 can reasonably be produced by a competent supplier.

The first step toward a solution is to convert the required lot mean life, μ, to a transformed value, μ_o. This new value, μ_o, is $\mu - \gamma$ or 5,000 - 2,000 which is 3,000 cycles. Next, from Table 1-F which gives conversion ratios for use when $\beta = 2$, one finds that for Sample Size Letter H and an AQL in p' (%) of 1.5, the ratio at the LTPD Quality Level is 38 and at the AQL it is 13.87. Since the plan is to be determined in terms of consumer's needs, the next step is to use the LTPD ratio to determine t_o. Thus (t_o/μ_o) x 100 = 38 or $(t_o/3,000)$ x 100 = 38. From this it is determined that t_o must equal 1140. By adding the value for γ (which is 2,000) to this latter figure, the required test time in absolute terms, t, of 3,140 cycles is obtained.

The related question of reasonableness of this plan for the producer may be answered by substitution of the test time just determined in the ratio for the AQL. The relationship is that (t_o/μ_o) x 100 = 13.87 or that $(1140/\mu_o)$ x 100 = 13.87. From this a value for μ_o of 8,240 cycles is obtained. This is then converted to original terms by the addition of the value for γ of 2,000 cycles. This gives an Acceptable Quality Level of 10,240 cycles. This is well below the level considered reasonable so no hardship will be imposed on the supplier.

<u>Note:</u>   The recent Department of Defense publication H-108[10] contains related plans based on the exponential distribution (Weibull shape parameter equal to unity) and using variables inspection instead of attributes. Plans have been made by the authors of this report to construct a set of variables sampling plans based on the Weibull distribution which should be available shortly.

APPENDIX - THE RELATIONSHIP BETWEEN p' AND t/μ UNDER THE WEIBULL MODEL

[The material in this appendix can be found in expanded form in Reference No. (1).]

The probability of an item failing prior to some specified time x is given by the cumulative distribution. If the lifelength, X has a Weibull distribution, this probability is,

$$P \{ X \leq x \} = 1 - e^{-(\frac{x-\gamma}{\eta})^{\beta}} \quad \text{for } x \geq \gamma; \quad ,\beta > 0.$$

$$= 0, \text{ otherwise.}$$

Here η (sometimes referred to as the characteristic life) is the scale parameter; β, the shape parameter and γ, the location parameter.

The mean (in excess of γ) of the Weibull distribution is,

$$\mu = \eta \; \Gamma(\frac{1}{\beta} + 1)$$

If p' represents the probability of an item failing prior to some test time t (in excess of γ), then,

$$p' = 1 - e^{-(t/\eta)^{\beta}} = 1 - e^{-[\frac{t}{\mu}(\frac{1}{\beta})\Gamma(\frac{1}{\beta})]^{\beta}}$$

$$\text{or} \quad \frac{t}{\mu} = \frac{[-\ln(1-p')]^{1/\beta}}{\Gamma(\frac{1}{\beta} + 1)}$$

which establishes the relationship between p' and t/μ under the Weibull Model.

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TABLE 1-A

Table of $(t/\mu_1) \times 100$ Ratios for $\beta = 1/2$

Sample Size Code Letter	p'(%) $(t/\mu_1)\times 100$	Acceptable Quality Level (AQL)													
		10.0	6.5	4.0	2.5	1.5	1.0	0.65	0.40	0.25	0.15	0.10	0.065	0.035	0.015
		.56	.23	83×10^{-3}	32×10^{-3}	11×10^{-3}	51×10^{-4}	21×10^{-4}	80×10^{-5}	31×10^{-5}	11×10^{-5}	50×10^{-6}	21×10^{-6}	61×10^{-7}	11×10^{-7}
A		66													
B															
C		19	29												
D		18	8.4	10											
E		13	7.3	3.6	5.4										
F		8.6	4.0	2.4	1.3	2.7									
G		7.1	4.0	2.0	1.2	.64	1.1								
H		4.9	2.5	1.4	.96	.59	.31	.42							
J		4.2	2.0	1.0	.60	.42	.26	.14	.22						
K		3.3	1.5	.74	.48	.28	.19	.12	.064	.11					
L		2.8	1.4	.69	.40	.20	.15	.10	.065	.034	.048				
M		2.2	1.1	.62	.29	.18	.089	.066	.047	.029	.016	.022			
N		1.9	1.0	.45	.24	.14	.082	.050	.037	.026	.016	.009	.012		
O		1.6	.78	.37	.20	.11	.062	.035	.022	.016	.011	.007	.004	.005	
P		1.2	.62	.29	.15	.068	.041	.025	.015	.010	.0060	.0041	.0025	.0013	.003
Q		1.1	.48	.21	.10	.045	.024	.014	.0084	.0047	.0031	.0019	.0010	.00060	.00031

$(t/\mu_1)\times 100$ at LTPD quality level [$P(A) = .10$]

TABLE 1-B

Table of (t/μ)×100 Ratios for β = 3/4

Sample Size Code Letter	p'(%) (t/μ)×100 →	Acceptable Quality Level (AQL)													
		0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
	(t/μ)×100 at LTPD Quality Level [P(A) = .10]	$67{\times}10^{-5}$	$21{\times}10^{-4}$	$47{\times}10^{-4}$	$84{\times}10^{-4}$	$14{\times}10^{-3}$	$29{\times}10^{-3}$	$53{\times}10^{-3}$	.10	.18	.31	.62	1.18	2.29	4.18
A															
B															101
C														59	44
D													30	26	43
E												19	15	24	34
F											12	7.2	11	16	27
G									6.8	4.5	7.0	9.7	16	23
H								3.5	2.8	4.3	6.0	7.6	12	18
J							2.2	1.6	2.5	3.4	4.3	6.4	9.8	16
K						1.4	.99	1.5	2.0	2.6	3.8	5.0	8.2	14
L					.80	.65	.99	1.3	1.7	2.1	3.3	4.8	7.8	12
M				.48	.38	.58	.79	1.0	1.2	1.9	2.7	4.4	6.7	10
N			.32	.26	.38	.53	.67	.83	1.1	1.6	2.4	3.6	6.4	9.4
O		.19	.15	.23	.30	.39	.47	.66	.95	1.4	2.1	3.2	5.2	8.5
P	.13	.076	.11	.15	.20	.28	.38	.53	.75	1.0	1.7	2.7	4.5	7.2
Q	.030	.045	.065	.097	.13	.17	.25	.36	.51	.78	1.3	2.1	3.8	6.5

TABLE 1-C

Table of (t/μ) x 100 Ratios for β = 1

Sample Size Code Letter	p'(%) / (t/μ) x 100 at LTPD Quality Level [P(A) = .10]	Acceptable Quality Level (AQL)												
		0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
	p'(%)	.015	.035	.065	.10	.15	.25	.40	.65	1.01	1.51	2.53	4.08	6.72	10.54
A															
B															
C															115
D														77	61
E													46	41	60
F												33	27	38	50
G											23	16	22	28	42
H										15	11	16	20	28	38
I									9.2	7.8	11	14	17	23	31
J								6.5	5.3	7.2	9.1	11	15	20	29
K							4.6	3.6	4.9	6.2	7.4	9.9	12	18	26
L						3.1	2.6	3.6	4.5	5.4	6.3	9.0	12	17	24
M					2.1	1.8	2.4	3.0	3.6	4.2	6.0	7.6	11	15	21
N				1.5	1.3	1.8	2.3	2.7	3.1	4.0	5.3	6.9	9.5	14	20
O			1.0	.86	1.2	1.5	1.8	2.1	2.7	3.5	4.5	6.2	8.7	13	18
P		.78	.52	.72	.91	1.1	1.4	1.8	2.3	2.9	3.7	5.4	7.6	11	16
Q		.26	.35	.45	.63	.79	.97	1.3	1.7	2.2	3.0	4.5	6.5	9.9	15

TABLE 1-D

Table of (t/μ)×100 Ratios for β = 1 1/3

Sample Size Code Letter	Acceptable Quality Level (AQL)													
p'(%)	0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
(t/μ)×100 at IAFD Quality Level [P(A) = .10]	.15	.28	.44	.61	.83	1.22	1.73	2.50	3.45	4.69	6.91	9.88	14.36	20.12
A	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	121
B	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	89	↓
C	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	61	↓	↓
D	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	47	↓	↓	75
E	↓	↓	↓	↓	↓	↓	↓	↓	↓	36	↓	↓	56	74
F	↓	↓	↓	↓	↓	↓	↓	↓	26	↓	↓	41	53	65
G	↓	↓	↓	↓	↓	↓	↓	18	↓	↓	28	35	43	57
H	↓	↓	↓	↓	↓	↓	14	↓	↓	21	27	33	43	53
I	↓	↓	↓	↓	↓	11	↓	↓	16	20	25	28	36	46
J	↓	↓	↓	↓	7.9	↓	↓	12	15	18	20	26	33	43
K	↓	↓	↓	6.0	↓	↓	8.9	11	13	15	19	23	30	39
L	↓	↓	4.8	↓	↓	7.0	8.9	11	12	14	18	22	29	37
M	↓	3.5	↓	↓	5.3	6.6	7.8	9.0	10	13	16	21	26	34
N	2.8	↓	↓	4.2	5.3	6.3	7.2	8.0	9.6	12	15	18	25	32
O	↓	↓	3.1	3.9	4.7	5.3	5.9	7.1	8.7	11	14	17	23	30
P	↓	2.1	2.7	3.2	3.6	4.5	5.2	6.3	7.5	9.0	12	16	21	28
Q	1.3	1.6	1.9	2.4	2.9	3.3	4.1	5.0	6.2	7.8	11	14	19	26

TABLE 1-E

Table of (t/μ)x100 Ratios for β = 1 2/3

Sample Size Code Letter	p'(%) (t/μ)x100 at LTPD Quality Level [F(λ) = .10]													
	Acceptable Quality Level (AQL)													
	10.0	6.5	4.0	2.5	1.5	1.0	0.65	0.40	0.25	0.15	0.10	0.065	0.035	0.015
p'(%) (t/μ)x100	29.01	22.15	16.42	12.33	9.07	7.08	5.46	4.07	3.08	2.26	1.78	1.37	.94	.57
A														
B														
C	122													
D	83	96												
E	82	65	70											
F	75	63	51	57										
G	66	52	45	37	46									
H	62	52	42	37	30	36								
I	55	46	38	34	29	24	27							
J	54	43	35	29	27	23	19	22						
K	49	39	32	28	23	21	18	15	18					
L	47	38	31	26	21	19	17	15	13	14				
M	44	36	30	24	20	17	15	14	12	9.8	11			
N	42	35	27	22	19	16	14	13	11	9.8	8.3	9.1		
O	39	32	26	21	17	15	13	11	9.9	8.9	7.8	6.5	7.2	
P	37	30	23	19	15	13	11	9.8	8.7	7.4	6.6	5.8	4.8	6.1
Q	35	28	21	17	14	12	9.6	8.2	6.9	6.1	5.3	4.4	3.8	3.1

TABLE 1-F

Table of $(t/\mu) \times 100$ Ratios for $\beta = 2$

Acceptable Quality Level (AQL). Body values: $(t/\mu)\times100$ at LTPD Quality Level [P(A) = .10].

Code Letter	Sample Size	0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
p'(%)		1.38	2.11	2.88	3.57	4.37	5.64	7.14	9.12	11.31	13.87	17.95	22.79	29.25	36.63
A															121
B														99	
C													77		
D												65			88
E											54			72	88
F										44			58	70	80
G									34			45	52	60	73
H								29			38	44	50	60	69
I							24			32	37	42	46	53	63
J						20			26	30	34	37	43	51	61
K					16			21	25	28	31	35	39	47	57
L				14			18	21	24	26	28	33	39	47	55
M			12			15	17	19	21	23	27	31	37	44	52
N		10			13	15	17	18	20	22	26	30	35	43	50
O				10	12	14	15	16	18	21	24	28	33	40	48
P			8.1	9.5	11	12	13	15	17	19	22	26	31	38	45
Q		5.8	6.7	7.6	8.9	10	11	13	15	17	19	24	28	35	43

TABLE 1-G

Table of $(t/\mu)\times100$ Ratios for $\beta = 3\ 1/3$

$(t/\mu)\times100$ at LTPD Quality Level [$P(A) = .10$]

Sample Size Code Letter	$p'(\%)$ $(t/\mu)\times100$ →	0.015 7.94	0.035 10.24	0.065 12.32	0.10 14.03	0.15 15.84	0.25 18.47	0.40 21.27	0.65 24.62	1.0 28.03	1.5 31.68	2.5 36.98	4.0 42.69	6.5 49.57	10.0 56.73
A															116
B														103	116
C												88	103	96
D											79	88	85	96
E										72	79	75	83	90
F									63	72	63	70	76	85
G								54	63	57	63	68	76	83
H							49	54	52	57	61	65	71	78
J						44	49	46	50	54	57	62	68	76
K					39	44	41	45	48	51	55	59	65	73
L				35	39	37	41	44	46	48	54	58	65	72
M			32	35	33	36	39	41	43	47	51	57	63	69
N		28	32	30	33	35	38	39	42	46	50	54	62	67
O	26	28	27	29	31	33	35	38	41	44	48	53	59	65
P	26	23	25	27	29	31	33	35	38	41	46	51	57	64
Q	19	21	22	24	26	28	30	33	35	39	44	49	55	62

TABLE 2
Table of $(t/\mu) \times 100$ Ratios at the Acceptable Quality Level (AQL)

β	Acceptable Quality Level - p' (%)													
	0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
1/3	56×10^{-12}	72×10^{-11}	46×10^{-10}	17×10^{-9}	56×10^{-9}	26×10^{-8}	11×10^{-7}	46×10^{-7}	17×10^{-6}	59×10^{-6}	27×10^{-5}	11×10^{-4}	51×10^{-4}	19×10^{-3}
1/2	11×10^{-7}	51×10^{-7}	21×10^{-6}	50×10^{-6}	11×10^{-5}	31×10^{-5}	80×10^{-5}	21×10^{-4}	51×10^{-4}	11×10^{-3}	32×10^{-3}	83×10^{-3}	.23	.56
3/4	67×10^{-5}	21×10^{-4}	47×10^{-4}	84×10^{-4}	14×10^{-3}	29×10^{-3}	53×10^{-3}	.10	.18	.31	.62	1.18	2.29	4.18
1	15×10^{-3}	35×10^{-3}	65×10^{-3}	.10	.15	.25	.40	.65	1.01	1.51	2.53	4.08	6.72	10.54
1-1/8	41×10^{-3}	88×10^{-3}	.15	.22	.32	.50	.76	1.18	1.73	2.49	3.94	6.02	9.37	13.98
1-1/4	94×10^{-3}	.18	.30	.43	.59	.89	1.30	1.92	2.71	3.75	5.67	8.31	12.38	17.74
1-1/3	.15	.28	.44	.61	.83	1.22	1.73	2.50	3.45	4.69	6.91	9.88	14.36	20.12
1-1/2	.31	.55	.83	1.11	1.45	2.04	2.80	3.87	5.16	6.77	9.55	13.13	18.31	24.71
1-2/3	.57	.94	1.37	1.78	2.26	3.08	4.07	5.46	7.08	9.07	12.33	16.42	22.15	29.01
2	1.38	2.11	2.88	3.57	4.37	5.64	7.14	9.12	11.31	13.87	17.95	22.79	29.25	36.63
2-1/2	3.32	4.68	5.98	7.11	8.36	10.27	12.39	15.06	17.90	21.08	25.90	31.35	38.28	45.82
3-1/3	7.94	10.24	12.32	14.03	15.84	18.47	21.27	24.62	28.03	31.68	36.98	42.69	49.57	56.73
4	12.21	15.10	17.62	19.62	21.71	24.68	27.76	31.35	34.93	38.68	44.01	49.59	56.18	62.85
5	18.72	22.17	25.10	27.36	29.67	32.87	36.12	39.81	43.40	47.09	52.21	57.45	63.46	69.44

WHICH ROAD TO SATELLITE RELIABILITY

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INTRODUCTION

Before getting into satellite reliability specifics, let's take a brief look at what makes reliability so difficult to achieve in reasonable periods of time. The problem arises in trying to achieve, by traditional tests and fix means alone, the reliability levels needed for today's complex systems.

The following figures illustrate these key points.

Figure 1, showing reliability level versus calendar time, is the well-known reliability growth curve. The reliability level rises rapidly at first, then more slowly and levels off late in development. The picture is essentially the same during production as manufacturing and field experience get incorporated into the design. It is important to recognize that regardless of how numerous and meaningful these fixes are there is a definite upper limit beyond which a given system design cannot be pushed.

This fact of reliability life is illustrated more specifically in Figure 2 which reflects a breakdown of failures at a point in time after System B was about 18 months in the field.

As noted, the top problem (which occurred only about once per 200 missions) contributes but 4.7 percent of all failures reported. In other words, if a 50-percent fix on this top problem were effected, the mean time between failure on the system only goes up about 2 percent. Looking at it in total, if a 50-percent fix on the top 69 problems were achieved, the system failure rate goes down only 28 percent.

This doesn't mean a 28-percent reduction in failures isn't meaningful to the user in terms of increased mission success rates and reduced maintenance. What it does mean is that many infrequent types of failures make reliability improvement of complex systems a slow expensive process.

The above examples (typical of today's airborne, missile or ground systems) reflect the reliability consequences of:

(1) increased complexity,
(2) unknown environments,
(3) compressed development and production schedules.

When you compound the above traditional reliability problems by

(4) limited numbers of high cost test prototypes,
(5) little (if any) orbital failure feedback,
(6) no orbital maintenance capability,
(7) multimillion dollar costs per launch,

the dominant role reliability assumes in satellite systems becomes apparent.

The remainder of the report has been divided into 3 parts. The first analyzes satellite reliability requirements in terms of both economic need and difficulty of achievement. The second part outlines technical and program reliability considerations. Described are both the technical reliability approach (required to assure that an adequate reliability level is designed into the satellite equipment) and the related reliability program plan (the various tasks and procedures necessary to implement the technical reliability approach). The third briefly summarizes the more important findings and conclusions.

SATELLITE RELIABILITY REQUIREMENTS

The amount of time, money, facilities and manpower invested in reliability (as any other key segment of development) can and should relate directly to the need versus the technical difficulty of achieving the levels required.

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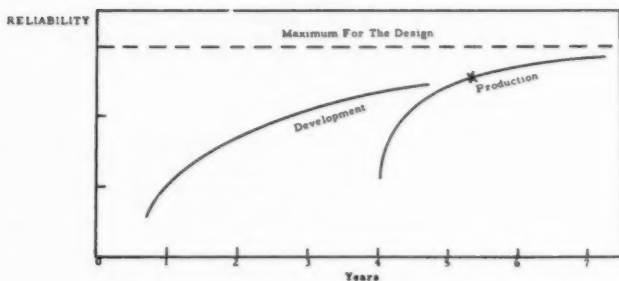
Figure 1 -- Reliability growth versus time.

Problem Rank	% of Total Failures
1	4.7
2	4.3
3	3.0
4	2.9
5	1.9
6	1.9
7	1.8
8	1.8
9	1.6
First 9 problems contribute	23.9
First 69 problems contribute	55.8
Remainder total	44.2
	100.0

Top 69 problems   =   55.8% of all Failures
50% Improvement   =   27.9% Reduction in System Failure Rate

Figure 2 -- System B reliability analysis.

Let us look at each of these elements in turn. First the need, that is to say, what reliability does the user require?

Granting the importance of satellite failures to critical military missions,* the overriding satellite reliability consideration is basically one of economics. By this we mean that unless exceptionally high levels of reliability are achieved, the costs of sustaining satellite systems becomes prohibitive. Figure 3, plotting satellite reliability versus first year costs illustrates this key fact. Various levels of one-year satellite reliability are shown in both percent and the more familiar MTBF (mean time between failures). The first year costs shown reflect initial launching costs plus the

costs of replacing failed satellites. The reader is referred to Reference [1].

To illustrate the economics of satellite reliability let's apply Figure 3 to a typical system. For example, a communication relay system in which four orbiting satellites are required to actively receive and transmit messages between a series of ground stations and/or aircraft.

As established by Reference [2] and shown in Figure 3, costs per launch are moderately fixed at $6,000,000.

Launching missile and associated orbiting guidance computer are each expected to achieve an 80-percent reliability. The probability therefore of a satellite being successfully orbited is .80 x .80 or .64, a figure which betters the 1959-1960 results

listed in Reference [3].

Fixing the above values permits us to then compare the first-year costs for a range of satellite reliability levels. To illustrate, let's cost out 40,000 and 200 hours MTBF reliability levels for satellites that have been successfully launched and orbited.

For 40,000 hours MTBF satellite reliability, Figure 3 shows that first-year costs total a tidy $45.6 million.

Since $45.6 million is not an insignificant sum, 40.000 hours MTBF as a minimum customer need does not appear unreasonable.

What happens if actual satellite reliability turns out to be only 200 hours between failures? This time, based on Figure 3, we see the system costs skyrocket to about $1.7 billion annually.

Although sustaining costs of this size would be prohibitive, the related 200 hours mean time between failure is not a pessimistic figure. On the contrary it is one of the

best reliability levels reported to date[4] for airborne equipment of comparable complexity and functions.

In other words, after looking at the reliability need in terms of operating costs, we are now seeing the other side of the coin, the technical difficulty of achieving the reliability levels required. Indicated is a reliability gap of about 200 times between current airborne communications equipment and the reliability required of essentially the same equipment, circuits, and functions enclosed in an orbiting, non-maintainable satellite.

Expressed in another way, the $1.6 billion first-year cost differential provides strong justification for planning, funding, and implementing comprehensive satellite development reliability programs.

TECHNICAL AND PROGRAM RELIABILITY CONSIDERATIONS

Previous sections of this report have spotlighted the serious problem of reliability in satellite systems. Shown was a gap of 200 to 1 between the best parts available today and the reliability levels needed to make satellites economically, as well as technically, feasible.

Traditional test and fix means alone just will not bridge this gap. Required instead (during the critical design and development phases) is strong reliability emphasis in two primary areas.

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* Such as ICBM early warning.
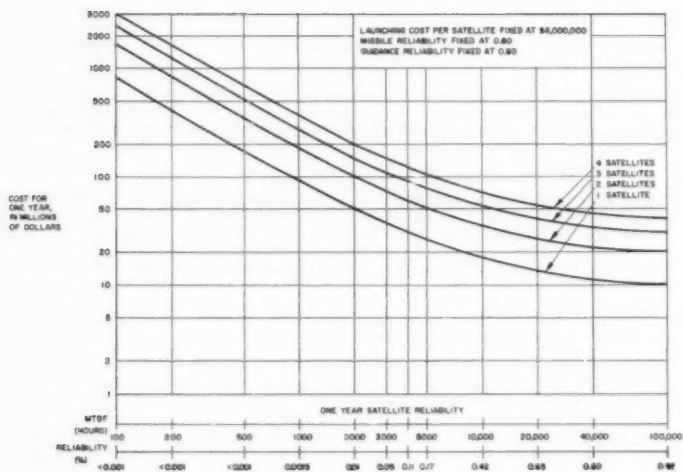
Figure 3 -- Operating costs versus satellite reliability levels.

First, a documented technical reliability approach that assures an adequate level of reliability is inherent in the basic design.

Second, a complementary reliability program plan that provides the means for implementing the technical reliability approach.

Before looking at each area further it is important to recognize that no one method, process, or control is a reliability cure-all. A good technical approach does not replace the need for complementary reliability program effort. For example, if any one part type in the satellite is not capable of withstanding the launch vibration, the redundant use of such parts by the designer would not help since all such redundant parts would fail concurrently and the satellite reliability would drop to zero.

Technical Reliability Approach

Because of the severe reliability requirements of satellite systems, specific development reliability ground rules must be formalized (on a project basis) before and not after design has begun.

Of particular importance (because they collectively control the maximum reliability level of a given design) are the 5 complementary areas covering reliability requirements, reliability prediction, redundancy applications, circuit design ground rules, and mechanical and environmental factors. Let's look at each in further detail.

Reliability Requirements--System analysis and tradeoff studies must first be conducted in order to establish design objectives that define a satellite system of maximum value at least total cost to the customer. In such studies, reliability must be treated quantitatively in order to permit realistic performance, weight, volume and total cost tradeoffs.

Once established, the overall satellite reliability requirements for launch, transition and orbit must then be allocated to subsystems and units. The requirements established for each phase and equipment level must be realistic, timely, and revised as necessary on the basis of initial and continuing reliability predictions or test results.

The end result (as shown in Figure 4) is to provide satellite reliability requirements in terms (such as mean time between failure) and at levels (subsystems and units) which are meaningful to responsible system and unit engineers.

Reliability Predictions--Preliminary and subsequent estimates of the reliability contributions of random part failures are required to establish the basis for system, subsystem, and unit design tradeoffs. The prediction methods used will vary depending upon factors such as the phase of development or new versus modified circuits. They can be based either on a synthesis of unit or subsystem reliability levels (from similar systems) or buildups of expected part failure rates times complexity[5]. Since thermal and electrical stress levels are major reliability factors, they should be introduced into the prediction picture as soon as this information becomes available or can be estimated.

If during the course of the satellite development program any of these estimates fall short of the required reliability levels, improvement must be achieved by increased cooling, greater derating, more reliable parts, and/or judicious use of redundancy.

Since previous sections have pointed out the wide gap between the reliability need and the best parts available today, it is apparent all of the above must be a part of any satellite system reliability effort.

The application of redundancy will be considered next. Circuit design, mechanical, and thermal aspects are covered in subsequent sections.

Redundancy Applications--Basic to achieving the high levels of reliability required of satellite systems is the judicious application of redundancy.

This might be on a part, circuit, or equipment level or a functional or sequential basis. By functional we mean that all redundant parts,[6] circuits, and/or equipments are operating continuously, while in the sequential case[7] another element gets turned on by remote or other means as the preceding one fails.
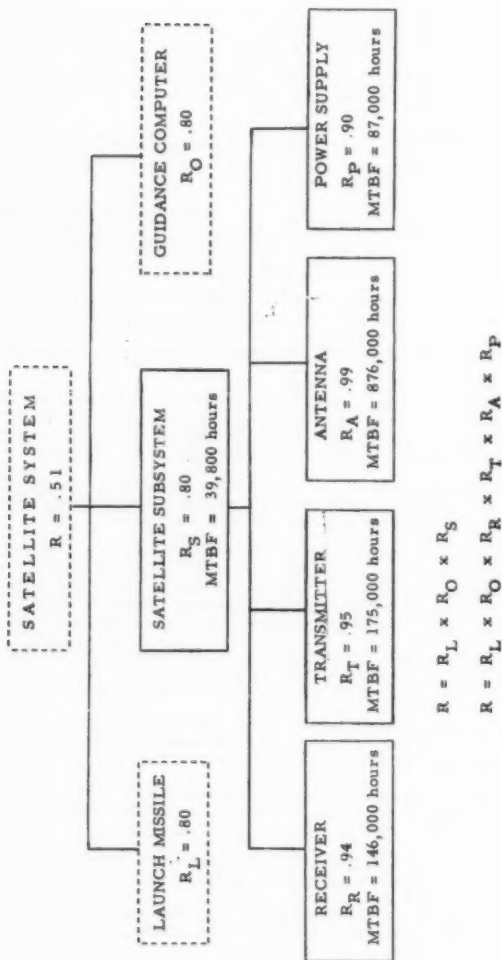
Figure 4 -- Satellite system reliability requirements for one year.

Since the use of redundancy (as all design techniques) has many pros and cons, every application must be thoroughly evaluated from both the mathematical and engineering viewpoints.[8] Some key considerations are listed below.

(1) What are the relative advantages of functional versus sequential redundancy for different part or unit life distributions?

(2) Reliability gains through part or circuit redundancy may be offset by inability to detect open connections not resulting in equipment failures.

(3) When part redundancy is applied to protect against catastrophic failures, what increased probability of degradation failure can be expected?

(4) Increased life testing and associated costs are required where part redundancy is used since part failures do not result in circuit failures.

(5) Weight, volume, and power disadvantages relative to reliability and cost gains should be compared for various types and levels of redundancy.

(6) Switching or storage life reliability effects associated with using sequential redundancy should be explored.

It is important to note that any one of the above factors could be controlling in a given satellite system. For example, where system performance requires the use of "short life"* power tubes, sequential rather than functional redundancy must be used to effect any large gain in satellite reliability.

Summing up, regardless of the hue and cry about increased weight and volume, redundancy, as shown in Reference [8], in the only design means capable of providing the equivalent of order of magnitude improvements in part reliability levels. Satellite reliability needs, therefore, justify and require considerable analytical and engineering effort in this key area.

Circuit Design Ground Rules--Formalized circuit design ground rules are required to eliminate or reduce actual or possible modes of failure prior to and not after the circuits have been finalized. Specifically, satellite design and development programs should include at least the following reliability ground rules.

(1) Maximum use (at the initial design stages) of parts qualified for expected environments and supplied by approved vendors.

(2) Utilization of all parts at 25 percent or less of rating to reduce random failures due to electrical stress.

(3) Utilization of all parts well within thermal ratings to minimize random failure and chances of exceeding part temperature limits.

(4) Marginal checking[9] of all circuits to minimize probability of degradation failures due to changes in part parameters with time.

(5) Maximum use of silicon rather than germanium semiconductors to minimize launch and boost thermal shock failures. Use of silicon devices also reduces possibilities of part temperature limits being exceeded during checkout tests prior to launch.

(6) Elimination of parts having short average life times and known wear-out characteristics (such as relays and power tubes[10]).

(7) Where redundancy has been applied at the part level,[6] detailed circuit analyses are essential to assure that whether a redundant part opens or shorts the circuit will still function.

As reflected in the above check list, exceptionally conservative circuit design practices are required in order to help meet satellite reliability requirements. Since backtracking is extremely difficult and expensive, they must be formalized for each satellite program before and not after design has begun.

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* Relative to mission length, e.g., 1000 hours relative to a year satellite reliability requirement.

Mechanical and Environmental Factors--Major mechanical and environmental factors affecting satellite reliability are listed below.

(1)   A heat transfer system that assures minimum part temperatures.

(2)   Use of redundant joints and connections.

(3)   Adequate environmental protection.

Let us examine each of the factors further. Because of the severe satellite reliability requirements and the direct relationship between part failure rates and ambient temperature, parts must be held at minimum (rather than traditional maximum) temperatures. Reliability predictions for typical systems clearly indicate that ambient temperatures in the range 25 degrees to 35 degrees C are required to provide part reliability levels consistent with unit and system needs.

Another basic reliability factor is the use of redundant joints and connections. The objective here is to achieve a low collective probability of failure for the thousands of joints and interconnections required in fabricating and assembling satellite systems. Although the use of redundant joints and connections is recommended practice in all types of satellite equipment, it becomes essential where redundancy has been applied at the part level. Without redundant joints and connections much of the gain resulting from part redundancy would be lost through the increased joint and connection failures.

As regards environmental capabilities, realistic design margins of safety should be incorporated to allow for environmental extremes (not averages) in the areas of vibration, shock, acceleration, etc. Of additional consequence are means of environmental protection relative to long term satellite systems exposure to solar radiation, micrometeorites and the vacuum of space.

Previous paragraphs have outlined the primary technical reliability requirements needed to assure that an adequate reliability level is inherent in the basic satellite design.

The next part describes the complementary reliability program plan, in other words the various tasks and procedures necessary to implement the technical reliability approach.

Reliability Program Plan
A satellite reliability program plan is best viewed in terms of the types of failures that must be predicted, prevented, detected, and corrected during the critical design and development period.

Specifically, the following failure contributors are recognized, the summation of which will effectively determine the reliability levels achieved by operational satellites.

        1.   Random part failures.
        2.   Degradation failures.
        3.   Part and unit environmental failures.
        4.   Failures caused by:
             a.   Packaging inadequacies.
             b.   Fabrication processes.
             c.   Poor workmanship.
             d.   Checkout procedures.
             e.   Storing and shipping practices.

Consistent with the severe reliability needs of satellite systems, this section has been divided into 9 parts covering reliability organization, time phased reliability programs, reliability design reviews, parts reliability, design and qualification testing, manufacturing reliability assurance, supplier reliability controls, failure reporting and analysis, and reliability training.

In effect we have listed above those major areas of reliability effort which are basic to any effective reliability program (satellite or otherwise).

The key difference is that many steps in the reliability program for a non-maintainable satellite are essentially irreversible. It is like a tightrope walker who makes 99 good steps (out of a possible 100) and one misstep. From the viewpoint of the

audience he tried his best and did 99 percent of the job. Taking a more practical look
at it, he had zero reliability.

Reliability Organization--Satellite reliability program needs require the full-time
directed effort of reliability specialists. This reliability group can be drawn from
a functional reliability organization and report to the project manager responsible for

the entire satellite program requirements. Major responsibilities[11] of the project
reliability group and supporting specialists would include, but not be limited to, the
following.

	In-Line	Advisory or Liaison
(1) Environmental Conditions Determination	X	
(2) Reliability Apportionment	X	
(3) Reliability Indoctrination	X	
(4) Parts Approval Verification	X	
(5) Specifications Review	X	X
(6) Design Review	X	X
(7) Failure Reporting Surveillance	X	
(8) Statistical Test Planning	X	X
(9) Statistical Test Evaluation	X	
(10) Human Factors		X
(11) Quality Control Coordination		X
(12) Program Data Evaluation		X
(13) Vendor Control	X	
(14) Flight Test Planning		X
(15) Analysis of Test and Flight Failures	X	X
(16) Determination of Corrective Action	X	X
(17) Corrective Action Followup	X	

Time Phased Reliability Programming--Time phased reliability programs are required for
each of the satellite subsystems. These schedules recognize that reliability is a
parameter that can be quantitatively specified, estimated, assessed and measured at
predesignated times in a system's design and development. A specific satellite reli-
ability program is shown in Figure 5. As outlined, the reliability program has been
subdivided into a number of specific reliability tasks and related tests. Start and
completion dates are also blocked out to permit measurement of progress as the program
proceeds. The completion dates are derived from, and consistent with, the master pro-
gram schedule.

Reliability Design Reviews--A system of reliability design reviews permits evaluation of
design reliability at sequential development stages. The objective here is the timely
detection and correction of actual or potential modes of failure prior to and not after
the design has been finalized.

Reviews (depending on the development stage) will include reliability evaluation of:

(1) Predicted versus required unit and system reliability levels (Figure 6)
(2) Redundancy applications
(3) Consequences of opens versus shorts in redundant part circuits
(4) Selection and use of approved parts
(5) Parts used well within electrical and thermal ratings
(6) Degradation failure calculations
(7) Design and qualification test results and related corrective action.

Parts Reliability--Because the part random failure rates required to meet the satellite
system reliability levels must be significantly lower than industry rates on comparable
equipments, heavy parts reliability effort and support is justified.

Parts reliability program areas considered essential to meeting this major reli-
ability objective are listed below.

(1) Development by components groups and use by designers of qualified parts lists.
(2) Development by components groups, use by designers and purchasing of approved
vendor lists.
(3) Complete qualification of non-standard parts prior to final design release and
orbital flight tests.
(4) Comprehensive analyses of all part failures.

Figure 5 -- Time phased reliability and test program.

See NAC Report R-67 for general instructions. Col. (4), measured values only. Cols. (7) and (9), indicate whether stresses are measured M, calculated C, or estimated E. Col. (11) is for use when components are grouped for early Inventories. Col. (13), indicate by X. Mandatory for all Inventories.										Inventory No. 000		Page 2	
										Revision 0		Section 5.1	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	
Circuit Symbol	Part Number (900,000, MIL, Tube type, etc.)	Component Family Name (As classified on failure rate charts)	Surface Temp. °C	Source (R-67, OEM, etc.)	Elect-Mech Stress	M, E or C	Temp. Stress °C	M, E or C	Unit Fail Rate	Number Used	Total Failure Rate	Non-Prediction	
7302	Jan 5840	Electron Tube		R-67	.87	C	65	E	2.93	1	2.93	
C311	907006	Capacitor, Button Mica		R-67	.80	C	65	E	.05	1	0.05	
C313	909046	Capacitor, Paper, Char. K		R-67	.50	C	60	E	.06	1	0.06	
C314	907006			"	.80	C	55	E	.04	1	0.04	
C314	907006			"	.60	C	65	E	.01	1	0.01	
C315	909046			"	.50	C	65	E	.02	1	0.02	
J301	922123	Connector - 18 Pins		"	---	-	---	-	1.0	1	1.00	
R308	953907	Resistor, Fixed Film		"	.30	C	65	E	.03	1	0.03	
R309	953907			"	0	C	65	E	.02	1	0.02	
CR302	1N157	Diode, Silicon		"	.50	C	65	E	.45	1	0.45	
CR303	1N157			"	.50	C	65	E	.45	1	0.45	
Total mean-time-between-failures — hrs.		19,800		Total failure rate - %/1000 hr.							5.06	

5.0 Proof of Design
5.1 Reliability Calculation
X Block No. 3
Entire Unit (Prelim. Inventories only)
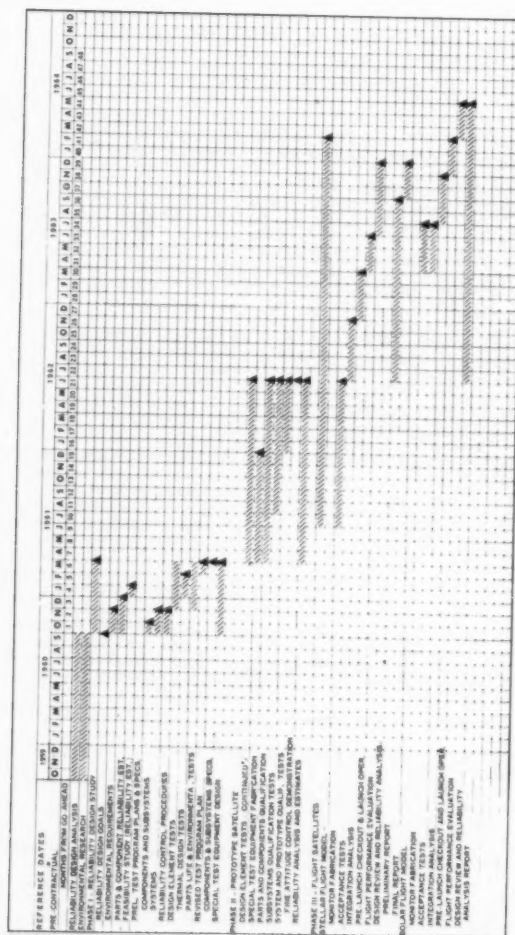
Figure 6 -- Reliability prediction worksheet

(5) Specialized parts tests in the following areas:

    (a) Non-destructive tests (e.g., infrared hot spot checks of resistors) to cull out potential failures.
    (b) Screening of parts parameters to minimize circuit drift failures.[12]
    (c) "Burn-in" of parts (such as diodes) to detect early part failures prior to assembly and to improve failure rates.

(6) Comparative vendor tests on high use parts. Significant reliability gains can be expected in this area since experience[10] has shown failure rates can vary by 25 to 1 for the same part supplied by different vendors.

Design and Qualification Testing--Regardless of how valuable the preceding reliability techniques and controls prove to be, functional, environmental and reliability testing will still be necessary.

The objective here is the timely evaluation and qualification of parts, units and systems prior to high cost orbital flight tests. Five sequential steps are involved.

(1) Establish functional, environmental and reliability requirements.
(2) Schedule manpower and facilities.
(3) Develop test procedures.
(4) Conduct tests, analyze failures, and improve design or processes.
(5) Approve and release qualified parts, units and systems.

Manufacturing Reliability Assurance--Increased quality control effort is necessary on satellite equipments to prevent or reduce failures caused by fabrication processes, material and part inadequacies or poor workmanship. In brief, reliability must be built as well as designed into satellite systems. Required are effective quality organizations and procedures. Some basic quality areas are listed below.

(1) Calibration of test equipment, tools and gauges.
(2) Control of non-conforming supplies.
(3) Suppliers quality programs.
(4) Drawing and change controls.
(5) Records of quality conformance.
(6) Training and certification of personnel.
(7) Receiving, in line, and final inspection and test.

In addition to increased emphasis in these basic quality areas, requirements peculiar to satellite programs include:

(8) 100 percent not sample screening of critical parts parameters,
(9) "Burn-in" of parts prior to assembly,
(10) Increased 100-percent application of non-destructive test methods,
(11) Segregation and "kid glove" handling of incoming and in process parts, materials and assemblies,
(12) Where part redundancy has been used, inspection and test techniques must be developed and applied for detecting part, joint, or connection failures within operable circuits.

Supplier Reliability Controls--In order to implement satellite system reliability levels, it is necessary to pass on to suppliers their share of the total satellite reliability requirements.

In the parts area supplier reliability controls involve 4 sequential steps.

(1) Survey and do business with only those suppliers capable of meeting the part reliability requirements.
(2) Carefully select and qualify parts before releasing for design application.
(3) Requalify samples from every shipped lot prior to assembly into satellite equipments.
(4) Rate the part supplier on the basis of qualification test results and reliability experience with parts received.

An effective program of subcontractor reliability control is also necessary. As previously outlined for parts, suppliers of major units and subsystems must be surveyed and rated. In addition, formalized time phased programs and reliability requirements and tests[13] should be established early in the subcontract development program. These

programs must be carefully monitored overtime by the cognizant design and outside procurement personnel in order to achieve timely integration of reliable subcontract equipment into the overall system.

Failure Reporting and Analysis--A system of failure reporting and analysis is a fundamental part of the laboratory, fabrication, and flight test phases of the satellite reliability program.

Early in the development period procedures that assure rapid failure collection and analysis should be established. Also required are cross-indexing methods for purposes of detecting recurrent failure modes or types, regardless of circuit, unit, or subsystem application.

Based on failure evaluation, supplier or internal responsibility must first be established and then corrective action initiated in terms of changed design, improved fabrication process, or a test procedure modification. Also of primary importance, due to multimillion dollar flight test costs, are the methods of followup that insure corrective action has indeed been accomplished.

Reliability Training--Since, as previously established, satellites require reliability levels several orders of magnitude better than today's best comparable equipment, it becomes important that project, engineering, and manufacturing personnel be made aware of the reliability programs objectives, needs, and methods.

The reliability training programs should include seminars describing the respective and complementary roles reliability design reviews, parts reliability, design and qualification testing, manufacturing reliability assurance, supplier reliability controls, failure reporting, and analysis, play in meeting the overall satellite reliability requirements.

SUMMARIZED CONCLUSIONS
The more important conclusions are considered to be as follows.

Exceptionally high levels of reliability must be achieved in satellite equipment because of multimillion dollar costs per launch and the replacement satellites needed to keep the system operational.

A comparison of satellite reliability need (in terms of operating costs) and the best parts available today indicated a reliability gap of about 200 to 1.

Traditional test and fix means alone just will not bridge this gap. Required instead to provide solutions to the satellite reliability problem, is strong reliability emphasis in two complementary areas.

First, a documented technical reliability approach concurrent with (not subsequent to) each stage of design and development.

Second, a related reliability program plan that provides the means of implementing the technical reliability approach.

In order to achieve satellite reliability levels of 40,000 hours mean time between failures the technical reliability approach must consider

(1) Part, circuit and/or equipment redundancy,
(2) Design application of parts well within electrical and thermal ratings,
(3) Minimum part ambient temperatures,
(4) Maximum use of qualified parts from approved vendors,
(5) Marginal checking of all circuits,
(6) Elimination of parts with known wear-out characteristics, and
(7) Redundant joints and connections.

Implementation of an effective satellite reliability program plan requires

(1) A full-time project reliability group for technical and programming purposes,
(2) Initial and continuing reliability comparisons of required versus predicted reliability,
(3) A specialized parts test program including screening, culling and "burn-in" techniques,
(4) Comparative vendor testing to establish the "best" source,
(5) Complete qualification of parts, units, and systems prior to orbital flight tests,

(6)   Increased quality control effort including the 100-percent application of non-destructive inspection and test methods,

(7)   Improved monitoring of supplier reliability programs,

(8)   Reduction of failure reporting, analysis, and correction cycle times during the critical design and development satellite phases, and

(9)   Training seminars to promote project awareness of the satellite reliability programs' objectives, needs and methods.

In summary, unless exceptionally high levels of reliability are achieved in satellite systems the costs of replacing failed satellites becomes prohibitive.   Outlined and discussed were the technical and program reliability considerations needed to make satellite systems economically as well as technically feasible.

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RELIABILITY INSTRUMENT PANEL

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Continuous control of product reliability requires measurement - both of achieved product reliability and of the tasks in a reliability program which eventually determine the final reliability of the product.

This paper first reviews the basic elements of reliability planning and control and then presents a measurement technique for control - The Reliability Instrument Panel.

RELIABILITY PLANNING AND CONTROL

To achieve a required level of reliability under operational conditions, a reliability program must include technical tasks to be performed by a variety of functions-primarily design, procurement, manufacturing, test, inspection, specifications and field support. Some of the tasks are new (i.e. reliability prediction) and some of them are established tasks which must be controlled better (i.e. process control during manufacturing) but the number of tasks is large and varied. It has been my experience that a program for a complex product will contain at least 30 individual tasks. In addition to the technical tasks there is also a management task of (a) establishing the program and (b) assuring the proper execution of the program. I believe that the measurement of task performance is a weak link in the management of reliability programs. To put the measurement phase in proper perspective, the basic management process underlying the efforts to make a reliable product should be examined.

Juran[1] has stated four conditions that must be present simultaneously in order to achieve control of a manufacturing process.

1. The operator must know what he is supposed to be doing.
2. The operator must know what he is doing.
3. The operator must have means for regulating the process.
4. The operator must feel that it is to his personal advantage to regulate the process to achieve good quality.

These four conditions are just as necessary for the individual technical tasks in a reliability program. (Furthermore, these points provide an excellent check list to detect underlying causes of weak areas in reliability programs). Here's what this means in terms of a reliability program (Figure 1 presents these four conditions in relation to the important distinction between planning, operations and control.)

1. The program must be defined.

Many companies have now been sold on the need for a reliability program and are now in the implementation phase. The first step in implementing a program is to completely define the program. This is really the planning phase of a reliability program. On a company wide basis, this means that reliability policies must be established and the reliability responsibilities of each organizational unit clearly defined. (Reference 3 shows an example of this.) Too much time is being wasted by reliability specialists arguing about the one best organizational approach. It is time that we realized that the reliability organization must be designed to fit within the operations of the individual company. The definition of responsibilities must be established and preferably in writing. If the reliability specialists within a company cannot reach agreement then management is left no alternative but to dictate the responsibilities. On a project basis, the individual reliability tasks necessary for the project must be (a) defined, (b) responsibility established for each task and (c) time schedules and budgets established. (A technique for defining the tasks in a

reliability program is shown in Reference 4.) Finally, standards of performance must be established not only for product reliability but also for the performance of the technical tasks in the program. Great strides have been made in establishing numerical standards of reliability performance for the product. Not only is a numerical reliability requirement set on a total system, but this requirement can be divided into sub requirements on individual subsystems thereby giving each design group a reliability number to design to-something they never had before. Making reliability a design parameter like weight is probably the most significant of the new reliability techniques. However, little has been done to apply the concept of a standard to other tasks in a reliability program such as qualification tests, design reviews, preparation of failure reports, implementation of corrective action for hardware failure, etc. I submit that the establishment of adequate standards of performance for all tasks directly or indirectly effecting product reliability is vital to achieving continuous control of a reliability program.

2. Performance must be measured and evaluated against the standard.

The measurement of performance in a reliability program should consist of three categories:

a. Measurement of product reliability against the reliability requirement.

This is, of course, the ultimate measure of the effectiveness of the entire program. It should be noted that product reliability measurement must not only include measurement of the end item but measurement to as low an item level (subsystem, chassis, etc.) as practicable in order to (a) isolate equipment problem areas and (b) collect data for use in preventing failures in future products.

b. Measurement of performance of tasks in a reliability program against a standard.

From the viewpoint of monitoring a program and preventing future failures, the measure of product reliability is not enough. All tasks that effect the final product reliability must be measured and controlled. The measurement of these tasks gives an indication of the final product reliability. Thus some of the potential problem areas can be detected before complete systems are built.

c. Audit of performance of tasks in a reliability program.

The performance of some tasks in a reliability program cannot be measured in numerical terms. For these tasks, audits should periodically be made to assure that the objectives and procedures originally developed are still appropriate and are being followed. Design review activity is a case in point.

The simple process of recording performance and feeding the information back to line personnel can be a powerful force in improving performance. The quality manager of an electrical connector plant once told me that he could almost guarantee a quick reduction in percent defective by posting a percent defective control chart in the production area. Furthermore the improvement took place before there was enough data to compute control limits and before the quality manager made any investigation. This indicates that the improvement was due to something much more basic than a statistical technique.

The measurement and evaluation phase is really the control phase of the program. The distinction between the planning phase (setting policies, defining responsibilities, procedure schedules, budgets and standards) and the control phase (measurement and evaluation) is important because it emphasizes that the two phases, although tied together by feedback, are separate and distinct. Reliability tasks defined to aid end product reliability are really a set of plans each of which must be accompanied by a specific means of control.

3. **A means for taking corrective action must be available.**

This is the operations phase of the program. In the case of product
failure due to a design deficiency, the responsible design group must
be provided with the time, funds, and staff help required to determine
the cause of failure and the corrective action necessary. In the case
of inadequate failure reports from the field, the field must be told
the specific inadequacies and instructed in correcting them. Again,
staff help may be required to help the line people correct the problem.

4. **Personnel must be motivated meet the standards of performance
established for their tasks.**

On a company wide basis, reputation is a powerful force. The possibi-
lity of incentive contacts and penalty clauses on reliability provide a
more immediate avenue. The hanging of rejection tags on equipment
which has passed all inspection tests but for which known reliability
problems exists will provide even more immediate motivation.

People inevitably underly all of the tasks in a reliability program.
The surface has only been scratched in developing effective means of
motivating people. Experience in the manufacturing activity shows that
financial incentives are not the complete answer. The variety of
personnel engaged in a reliability program make the task of motivation
a difficult one.

THE RELIABILITY INSTRUMENT PANEL

The key part of the control phase is the measurement of performance of (a)
product reliability and (b) performance of key functional tasks in the program.
I would like to propose a Reliability Instrument Panel [5] to measure and report
this information. In essence, the R.I.P. will be a listing of results for a
number of indices representing tasks that directly or indirectly effect product
reliability.

The development of a useful Reliability Instrument Panel presents a real
challenge to the reliability engineer. Here are some critical points to examine.

1. **Development of adequate performance indices.**

The development of numerical indices is the heart of the problem, par-
ticularly for reliability tasks that do not lend themselves to quanti-
tative measurement. The following criteria for indices are critical:

a. **Ease of understanding.**

The index must be simple and clear. When this is not possible
(and this will be so for many steps), it is better to omit an
index entirely than invent an arbitrary and/or complicated index
merely for the sake of having an index. Gaining acceptance of the
basic concept of performance measurement is more important than
having a complete set of indices. More complicated indices can be
added later if the need is critical and preferably in answer to a
request from the affected organizations.

b. **Ease of data collection and computation.**

The effort required to publish the report must be reasonable in
order to (1) publish the report frequently and on a timely basis
and (2) permit the reliability specialists to have time to execute
their regular functions in reliability.

c. **Completely valid for the task to be measured.**

Complete validity is essential if an R.I.P. is to be an effective
tool of reliability control. It would indeed be tragic for any
control system to degenerate into arguments between line and staff
personnel on whether or not an index gives a "true" picture of per-
formance. Again, it would be better to omit an index rather than

jeopardize acceptance of the basic concept by using an index that
is only partially valid.

Ideally, the control for each task in a program should include a
quantitative index for evaluation. To achieve this, it is neces-
sary to define the task in very specific terms. A criterion for a
proper task definition should be the ability to evaluate the per-
formance of the task and perhaps even the ability to establish a
quantitative index of performance.

2. Development of numerical standards of performance.

For each index developed for the Reliability Instrument Panel, a stan-
dard value for the index should be established. A key point is this:
the people responsible for the activity should set their own standard.
At first glance, it might seem that this would result in very loose
standards. Actually, this often results in a tighter standard. More
fundamental, however, is the question of corrective action. Real
effort to take corrective action to meet a standard is much more likely
when a standard is self-imposed rather than established on the basis of
higher authority.

3. Reporting of the effect of poor reliability performance on schedules
and costs.

Decisions on any project must be made by drawing the proper balance
between reliability, production schedules, and overall project costs.
In the case of critical failures, there is no problem in convincing
Management that corrective steps must be taken even if delivery delays
and increased costs will result. However, the reliability engineer is
often faced with selling management on a phase of the program or a hard-
ware fix that either has only a minor effect on final reliability or
only indirectly effects reliability. If the recommendation is not
accepted, the reliability engineer is prone to criticize management for
its failure to appreciate the importance of the problem.

It seems to me that the basic fault lies with the reliability engi-
neer's failure to present the case in terms familiar to management.
With each recommendation, must be presented the effect, in quantitative
terms, on reliability, schedules and costs. It is not always possible
to show numerically the effect on reliability. In these cases, it is
only natural for management to place more weight on the schedules and
cost factors because invariably someone is able to estimate increased
costs and schedule delays. Now here is the key point: most recommen-
dations made to increase reliability will result in lower total program
costs and less delay in the total schedule in the short or long run.

The real challenge to the reliability engineer is to turn the cost and
schedule factors from being his enemies to being his tools to sell
management. This can be done by estimating for management the dollars
and time that is currently being lost due to the program weakness that
the reliability engineer is trying to correct. (Projecting the current
rate of loss through to the end of a time period or the end of a cont-
ract can be a particularly powerful tool for convincing management.
Computer simulation techniques as applied in PERT, for example, are a
fascinating possibility.)

Table 1 shows a possible format for a two page Reliability Instrument Panel
for a specific project. The form provides for the indices, organization resp-
onsible, a standard for each index, current performance, performance last month,
and statements on the effect of performance on product reliability, schedules
and costs. The indices finally selected will depend on project needs and
company practices. The list in Table 1 is presented to provide ideas to reli-
ability engineers throughout industry.

CONCLUSION

The Reliability Instrument Panel will provide line supervision and top
management with a continuous picture of performance so that steps can be taken

early enough to prevent serious problems from developing. This, in turn, will help assure that reliability remains free from the concept of "management by drives". (One month there is a drive for lower costs, and costs are lowered, for a while at least. Next month, the drive is for a better safety record.) <u>Lasting improvements in reliability can only be achieved when continuous control rather than sporadic fire-fighting is achieved.</u>

LCS Code   800:00:419

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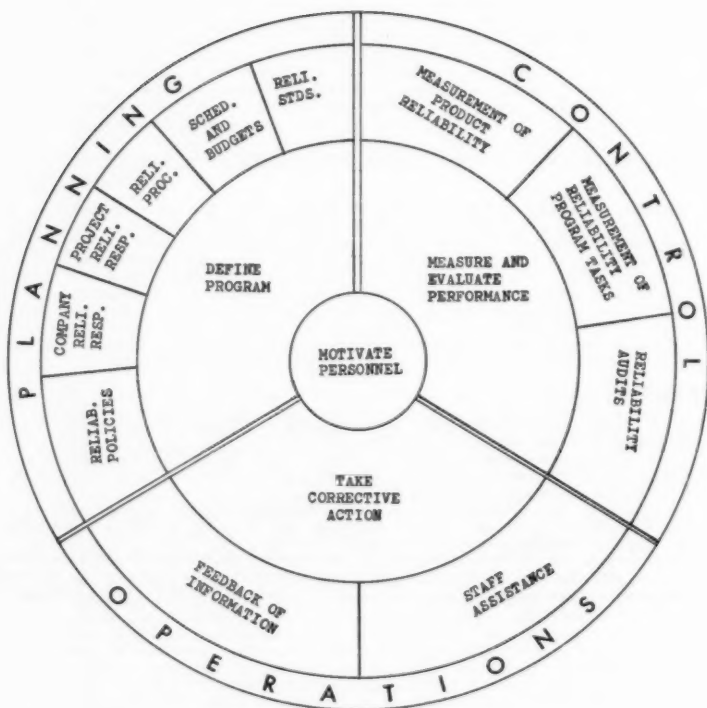
Fig. 1

Table 1

RELIABILITY INSTRUMENT PANEL

Project _____   Month of _____

Performance Index	Responsibility	Standard	Performance		Effect on Final Product Reliability, Costs, and Schedules if Current Performance Continues
			This Month	Last Month	
1. Achieved reliability. Overall system MTBF Sub-system A: MTBF B: MTBF etc.					
2. No. of parts added to design during period.					
3. Percent of part qualification tests completed.					
4. Percent of future qualification tests for which test procedures are approved.					
5. No. of drawings omitting burn-in and/or replacement period when required.					
6. Percent of parts rejected at receiving inspection.					
7. No. of cold solder joints reported during inspection (as an example of a specific manufacturing problem).					
8. No. of discrepancies between drawing and equipment at final inspection.					

RELIABILITY INSTRUMENT PANEL (Cont'd)

_____ Project   Month of _____

| Performance Index | Responsibility | Standard | Performance | | Effect on Final Product Reliability, Costs, and Schedules if Current Performance Continues |
			This Month	Last Month	
9. Average number of physical defects per unit at final inspection.					
10. No. of additional defects found per unit during check · inspections.					
11. No. of handbook errors (effecting product performance) per 100 pages.					
12. No. of trouble reports received.					
13. Percent of trouble reports inadequately filled out.					
14. Average time between writing of trouble reports and receipt in reliability group.					
15. Average span time for "fixes" to be incorporated.					
16. No. of part replacements made by taking parts from other completed units due to lack of spares.					
17. No. of unresolved problem areas at end of month.					

MYTHS AND REALITIES IN RELIABILITY

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INTRODUCTION

Many existing concepts about reliability are either unrealistic or incomplete. There is usually an element of truth in each, but a framework of myth is frequently established around it which misleads the hearer or reader. Sometimes meaning of words is the basis for the myth. Other times conclusions are drawn on inadequate evidence or based on statements withdrawn from context.

This paper considers several of the common myths in turn and discusses some clarifying facts.

DISCUSSION

Myth #1
Reliability is not a basic military or national defense problem. It is just a fad that will blow over if industry sits tight and keeps on making its usual good products.

- The seriousness of unreliability in complex systems is very real to those who have tried to improve system reliability to satisfy existing field needs. Quotations from responsible authorities will prove this point:

Quoting from a December 10, 1959 report by Mr. J. M. Bridges, Director of the Office of Electronics, Defense Department, Washington, D. C. to the Defense Science Board: "Poor reliability is one of the most serious limitations in obtaining acceptable operational effectiveness in military systems."

Quoting from a report by Mr. N. E. Golovin, Director of Technical Operations Division, Advanced Research Projects Agency, Washington, D. C. to the same meeting of the Defense Science Board: "The forecast of operational feasibility for any (complex) system must be a relative one with respect to the integrated effects of cost and over-all system reliability in competitive alternatives."

Quoting from an address by Vice-Admiral J. T. Hayward, presented to the 6th National Symposium on Reliability and Quality Control held in Washington, D. C. on January 12, 1960: "The unreliability of complex systems and their component parts is one of our major national problems."

Quoting from a paper by Capt. Emerson F. Fawkes, USN, Assistant Chief of Staff (Material) presented at the 3rd Navy-Industry Conference: "We in the fleet daily receive millions of dollars worth of unreliable equipment.....its usefulness is badly compromised." "...in spite of all efforts to improve reliability of our weapon systems, increasing complexity is creating an ever-increasing reliability deficit."

Excerpting information from a paper given by the U. S. Navy Commander C. O. Holmquist, Office of Assistant Secretary of the Navy (R & D) at the 3rd Annual Navy-Industry Conference, 1959: (1) Aircraft average availability in the fleet has dropped from a near maximum (maximum of 80% based on Navy turn-around and preventative maintenance program) of 79.5% operating aircraft available (propeller type) in 1951 to about 55.6% average for the more complex jet types in 1959. (2) Typical complexity of electronic gear for fighter aircraft has risen from less than a hundred parts in 1941 to over 8,000 electronic parts in 1959. (Based on an approximate figure of 10 parts per tube). Reliability and maintenance are thus serious problems today. (3) The average maintenance figures on the more complex current fleet aircraft range to as high as 72 maintenance man hours for each flight hour. This contrasts with the less than 5 to 1

ratio common just a few years ago.

From this it can be seen that reliability is a major national problem and not a fad that will blow over.

Myth #2

There is no real problem in making most modern systems reliable. Consider, for example, the automobile or the average television set.

- Let us consider the automobile. The average family car is driven 10,000 miles a year and is replaced before four years of use as worn out. This means the average longevity of the family car is 40,000 miles or at a 30 mph average, 1,330 hours of operating time. Suppose that in this four years you replace two sets of tires, two fan belts, five sets of 8 spark plugs, a battery, three sets of points, one set of brake linings, and two essential motor parts such as a fuel pump. With no more repairs than this in four years the average family would consider their car very reliable. Yet even considering each set of parts such as 4 tires, 8 spark plugs, etc., as one failure event, this story includes 12 failure events. The mean time between failures for this "reliable" family car is thus only (1,330/12) 110 hours MTBF.

Now if all the failed parts are considered as individual items, such as is frequently done in military field reporting programs, the total mean time between failures for this "reliable" car would appear to be 1,330/60 or 22 hours.

We all are familiar with the unfortunate cases of cars which are production "lemons". Such cars may exhibit five to ten times as many failures as those enumerated for the typical "reliable" car. The mean time between failures for these on the total failed item basis would approach a 2 hour figure.

We thus see that the so-called reliable family car may exhibit a MTBF of between 2 to 125 hours. On this basis the military requirement for equipment with a MTBF of from 500 to several thousand hours is a severe requirement. The reliability of complex systems is a real problem.

Myth #3

The average company can accomplish all that is necessary in reliability without any special program.

- The average company operates now as it has in the past with a so-called good practices approach. This must be replaced by a controlled operation if reliable complex systems are to be produced.

The differences between the good practices approach and a controlled operation and how to achieve the conversion are subjects for other papers. Indeed, the "how to" portion of this is today one of the major problems of industrial management.

In brief for this presentation, these are changing times. Products are changing, techniques are changing, and organizational approach must change to keep pace. A formal program for reliability control and product assurance is a must for the success of all future projects involving complex systems. A brochure on the RCA Product Assurance Program to meet this need is available on request.

Myth #4

If you try to measure the reliability of your product you just run the cost up to where you are out of business.

- In the near future the only companies left in the business will be those who know and are able to control the reliability of their product. The first step on this road to survival is to establish methods and procedures for reliability measurement. Rather than being a matter of not being able to afford reliability measurement, the situation is rapidly becoming one in which no company can afford not to make them. Reasons for this will be discussed in connection with other myths.

Myth #5

It is impossible to design and develop a new system to a specified numerical reliability figure. Reliability must grow as experience is gained from use.

- There are two aspects to discuss in connection with this myth:

(1) It is now possible to design new systems to a specified numerical reliability figure. There is less information and empirical data to use as guidelines on some types of systems than others, but the basic techniques and controls are available. Multiple sequential feedback of analyzed information and control in specific stages with design reviews are some of the modern tools of controlled operation.

(2) Those who depend on a reliability growth as a product progresses through various stages of manufacture and use are using the good practices approach. This is the expensive and outmoded method whereby corrective action is after-the-fact and the major effort is expended in "putting out fires" as they spring up. The economy of the opposite approach or controlled operation derives from taking deliberate advance measures to prevent "fires" from occurring. This requires a team analytical approach for doing the best things in the right way at the right time.

The best and least expensive equipment is that which was designed right the first time with careful consideration of all the end-use factors, human limitations, and production problems.

Myth #6

Good company practices of yesterday will achieve reliability today if strictly adhered to.

- A simple answer to this is that the good practices of today and tomorrow are not the same as the good practices of yesterday. It is unfortunately true that many known poor practices of yesterday are still being practiced in parts of industry today. These must first be eliminated and replaced with a controlled operation based on the new good practices which are quite different.

Myth #7

Presently available parts are good enough to meet any reliability requirement if the circuits are designed properly for optimum application of the parts.

- It is true that many reliability failures in existing equipment can be traced to the misapplication of parts. Overloading and bad environment can make an otherwise good part perform unreliably. But the limiting factor today in the reliability of complex systems is that even with optimum application and maximum derating available, parts simply are not good enough.

Consider the former illustration of the family automobile. Most modern cars make the best possible use of available parts. To greatly extend car reliability would require the development of better parts such as better batteries, better tires, etc.

Myth #8

We have an experienced procurement operation and can get anything we need. If "better parts" is the answer, all we have to do is specify them to our suppliers.

- This raises the question of a real dilemma which exists in modern procurement. Do you specify to your suppliers the exact high reliability you know you need when this is above the state-of-the-art and you know you will have to waive the requirements in order to get anything at all, or do you order what you know you can get, knowing full well that this will not result in the system reliability you need. There is no pat answer to this dilemma nor can there be until the problem is solved by the availability of better parts with measured better reliability.

Myth #9
    You will get a reliable product if you design to use only mil stand-
ard parts.

    - This is a complete fallacy because of the wide range of relia-
bility that exists in presently available mil standard parts. Even with
the best application and maximum possible derating, many available mil
standard parts have very poor reliability. The existing part specifica-
tions are inadequate to insure reliability.

Myth #10
    The military Q.P.L. list is a sound basis for picking your sup-
pliers.

    - This is a myth because the existing Q.P.L. list means only that at
'one time, and perhaps on one batch which might have been handmade and
hand picked, suppliers were able to qualify. In many cases the qualifica-
tion requirements have changed, the qualification requirements for your
job might be different, and the suppliers may not be able to provide the
same reliability on subsequent batches. The Q.P.L. list is a good start-
ing point only to pick suppliers.

Myth #11
    Such highly contradictory specifications for reliability are coming
out of the military services that if you comply with one you can't comply
with any of the others.

    - If this situation exists in your operation then your original
method of compliance was probably improper. In most cases a program for
controlled operation can be implemented to meet any of the new specifica-
tions.

Myth #12
    Until someone really defines reliability, there is no point in my
company taking it seriously.

    - The answer to this myth can be illustrated by a cartoon showing
the living room of an exclusive men's club for retired millionaires.
Seated about in a circle of over-stuffed chairs are a group of bored
discussants. But contrary to the usual quiet and sedate background, every
door and window is pouring in thick angry woodsmoke. Instead of scrambl-
ing to find some exit throught the obviously surrounding fire, the dis-
cussion leader quietly asks one of the other reclining members: "And
George, how would you define smoke?"

    The moral of this is that if you are prone to wait for a good defi-
nition, it may already be too late to escape the fire.

Myth #13
    As in the past, free enterprise in connection with the law of supply
and demand will provide whatever is required for us to successfully meet
the reliability demands of the future.

    - The myth in this statement probably hinges around the word "us".
Free enterprise and the law of supply and demand will undoubtably provide
an answer, but not through and for those who wait to feel the pinch of
economic dire necessity. Too little and too late is apt to describe their
situation. Those who take the cue and lead the pack will get the juicy
worms.

Myth #14
    Recent past history has shown that the U.S.A. is well ahead of the
rest of the world in the field of reliability control.

    - The personal experience of the author in Europe on repeated speak-
ing tours and the experience of many experts traveling to Japan and the
Far East indicate that the U.S.A. is not far ahead. In fact, at the rate
of progress in these foreign lands we can be left far behind in the near
future unless we look to our laurels. I believe this is true not only
in regard to reliability, but to production capacity and price. Our

vaunted lead in production capability is being severely challenged.

Myth #15

Industry has always been faced with the need for reliable dependable products. Management as always must pass this responsibility on to its technical organization and not get involved.

- This myth hinges about the fact that top management is involved in reliability whether the individuals realize it or not. Every management decision has implications for the ultimate reliability of the product. The effectiveness of the operation, the efficiency of the organization, the emphasis of the programs, the spirit of compliance to specifications, and the morale of the men all follow the example set at the top. Management has a big hand in reliability and must make every decision with an awareness of its impact on reliability.

Myth #16

Some products are just naturally better than others, and how to specifically control reliability is still mostly a mystery.

- It is true that some products are better than others for inherent reasons. Usually factors such as simplicity of function and type of application will explain the differences. But there is very little mystery left in reliability. Lack of information exists still in a few areas, but methods of control are thoroughly worked out.

Myth #17

Reliability is just another quality characteristic that has to be controlled; therefore, quality control is basically responsible.

- A loose usage of the word "quality" makes it synonymous with the word "characteristic". Any quality of a product is thought to be any characteristic that has to be controlled. Since reliability is a product characteristic that has to be controlled, then, ergo, this loose thinking makes reliability a quality characteristic. Usually, the people that use this type of logic also conclude that since their quality control organization was established to control quality, then it must obviously be responsible for reliability.

There are some officials in the ASQC who visualize the entire field of quality control in this generalized way. However, according to an analysis of the field in 1959 by Professor Ellis Ott of Rutgers University more than 85% of the profession are engaged in the historic field of factory process and machine control. In the electronic industry this percentage is probably much higher than 90%. In other words, contrary to what some wishful thinking would have it be, the profession of quality control is actually one of controlling the uniformity of a factory output to meet certain performance criteria as specified by engineering. Thus, reliability is only a quality characteristic if it is so specified and to the extent specified on the drawings. And the best quality control effort cannot achieve any higher reliability in a product than is inherent in the design on the drawings.

It has been proven many times that a good quality control operation can result in the production of a very uniform high quality item that is very unreliable. The product can be uniform and comply fully with the specifications, but be very unreliable in use. Highly purified medicine compounds might be given as a perfect non-electronic example of end use affecting reliability completely out of relation to the quality of the product. The quality is important, but it is only one factor in reliability.

Many other examples in all industries can be given to show that reliability is not just another quality characteristic unless this term is used in an unrealistic loose fashion.

Myth #18

Total quality control is the answer to achieving reliability.

- This concept is usually accepted by those who are thinking in the

loose terms of reliability being a quality characteristic to be controlled
but whose experience tells them that the normal functioning area of qual-
ity control is not broad enough to do the job. Not wishing to drop the
word "quality" for the better term "characteristic" they add the word
"total" to indicate that they mean something greater and quite different
from quality control. They are thinking in terms of an over-all manage-
ment control program which extends into all other departments of a company
in addition to production. They will clarify this concept by the explana-
tion that they are referring to a cradle to grave control operation. This
operation starts up in earliest planning and has implications and inputs
throughout every phase of development and manufacture and affecting every
department including marketing, engineering, and through into field ser-
vice.

But there are some people who point out that the founding fathers of
ASQC thought of their profession in this broad cradle to grave perspective
and, therefore, in this broader artificial sense the added word "total" is
unnecessary. By this argument the need is to convert the entire quality
control profession to what the proponents of the concept mean by total
quality control. The question then remains as to what you would call the
present occupation and profession that guarantees a chemical purity to
aspirin tablets. Presumably this could be accomplished by an upgraded
inspection function and the establishment of a new profession entitled
"Inspection Engineering". This new profession would take over the jobs
now performed by quality engineering. Process control criteria, inspec-
tion method planning and the analysis of factory failures, plus other fac-
tory oriented quality engineering functions would be shifted to this newly
titled specialty. Quality control engineering then would shift over to
perform the functions now provided by such specialties as management engi-
neering, operations analysis, and program and budget analysis, etc. The
advantages of all this shifting of titles and duties to preserve the orig-
inal intent of quality control seem doubtful. A more logical approach
would seem to be the recognition of the important contribution that qual-
ity control makes to process control and product uniformity and not try to
convert the established profession to something it is not. In fact, most
existing quality control operations could benefit greatly by professional
improvement in the historic areas of process and factory control without
expanding into other fields of activity.

But is total quality control in the new sense really the answer to
achieving reliability? Agreed that the historic field of quality control
is in the factory; it can be readily shown that this function is affected
by design decisions, contractual aspects of marketing and even pre-project
customer planning. Thus, it can be granted that good quality control in
its established factory control sense is always a cradle to the grave
function. For example, a specific design might be much easier to produce,
and, thus, result in a more uniform functional product than another functionally com-
parable circuit. Again, if the process capabilities are considered during
the product design stage, the job of quality control can be made much eas-
ier. And a third example, unless provisions are made in the contract to
perform the various quality control functions these cannot be implemented
when the project reaches the production stage. So there are cradle to
grave or total quality considerations which are important to the success
of the usual type of quality control. But none of these factors necessar-
ily control reliability or can assure that a product will meet a specified
reliability goal. Other proof can be given that the total quality control
concept is not the answer to reliability.

Without going into this in detail here, it should be emphasized that
reliability, maintainability, value and other product characteristic con-
trol programs are also all cradle to grave control specialties. They all
have implications and inputs at every project phase and to every depart-
ment of each company. Their major differences are in type of execution
related to the development stage of the project in which their major con-
trol is exercised, and to the type of manpower and specialist training
needed to perform the work. In the majority of cases the established
quality control people do not have either the interest, training, back-
ground or experience to work successfully in fields other than their
native factory process control field. To make these people responsible
for reliability and other related product characteristics in other than

the factory production stage is unfair to them and is not realistic management.

Myth #19

Reliability can be achieved by appointing a reliability coordinator under a design integration leader in engineering.

- It is true that a great deal of reliability engineering must be performed at the working engineering levels. But just as quality control in its established factory sense has cradle to grave implications so does reliability control. Therefore, it is essential that reliability policy and top reliability control be established at an organizational level with influence and authority across all the departments not just in engineering.

It has been stated that there are a dozen or more cradle to grave control specialties such as reliability, maintainability, value, quality, system integration, etc. It follows that no company can afford a dozen or more across the board control operations. There can be only one, and this must be an organization with a program to give assurance to management and to the customer that total quality, total reliability, total value and other total control efforts will be exercised as needed. The RCA program for this is called product assurance. A booklet describing this is available on request.

Myth #20

We have appointed reliability coordinators and sent people off to training conferences and symposia. We are doing all we can to support reliability.

- The answer to this is that I have yet to see a control operation that is as good as it could be. Until completely controlled operations become the rule rather than the exception, a great deal of work remains to be done. Fortunately, many of these efforts more than pay their way in dollars saved.

Myth #21

All sorts of test, measurement, and control schemes have been proposed for every phase of the company operation. We simply can't afford such a full reliability control program. Reliability is too expensive.

- The cost of reliability can be discussed in four parts. Each one of these parts is important and has far reaching implications. All four will be discussed here because of their importance. They are listed on Slide #1.

DOING THE JOB AT THE LOWEST COST

        A. Overall cost picture
        B. Timing of expense
        C. Project cost accounting
        D. Value engineering

- Slide #1 -

A. Overall Cost Picture -- The Slide #2 shows a curve plotting the relationship between initial cost and level of reliability. Obviously, if we are building an equipment with low reliability we can produce this at a fairly low cost; however, if we are trying to build a very high reliability equipment, then the initial cost must be quite high. This is, of course, what makes the problem so difficult when somebody comes to you and says: "How much will it cost to complete a reliability program on this project?". You have to come back with the question "How much reliability are you talking about?". Obviously, if you are talking about a reliability which is going to raise the state of the art, then the particular cost of that particular equipment has to be very, very high initially. But the compromise to this is shown in the next Slide #3.

Slide #3 shows the other side of the picture - the support cost. The support cost is bound to be very high if you are selling equipment

THE COST PICTURE

- SLIDE #2 -

THE COST PICTURE
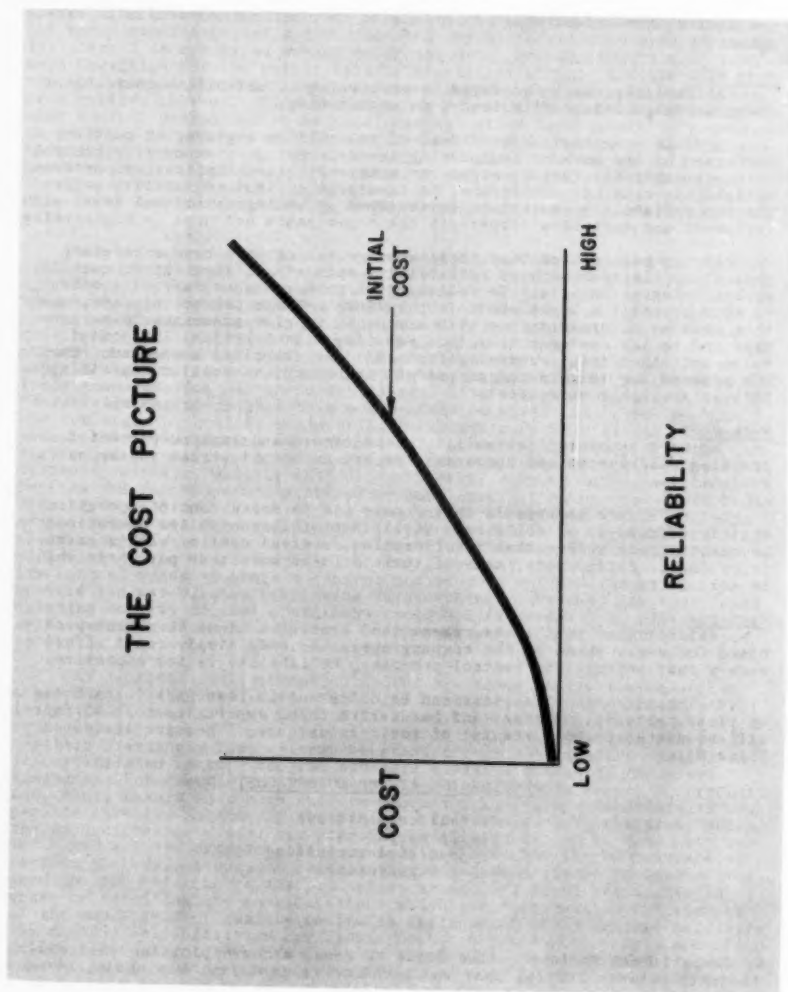
- SLIDE #3 -
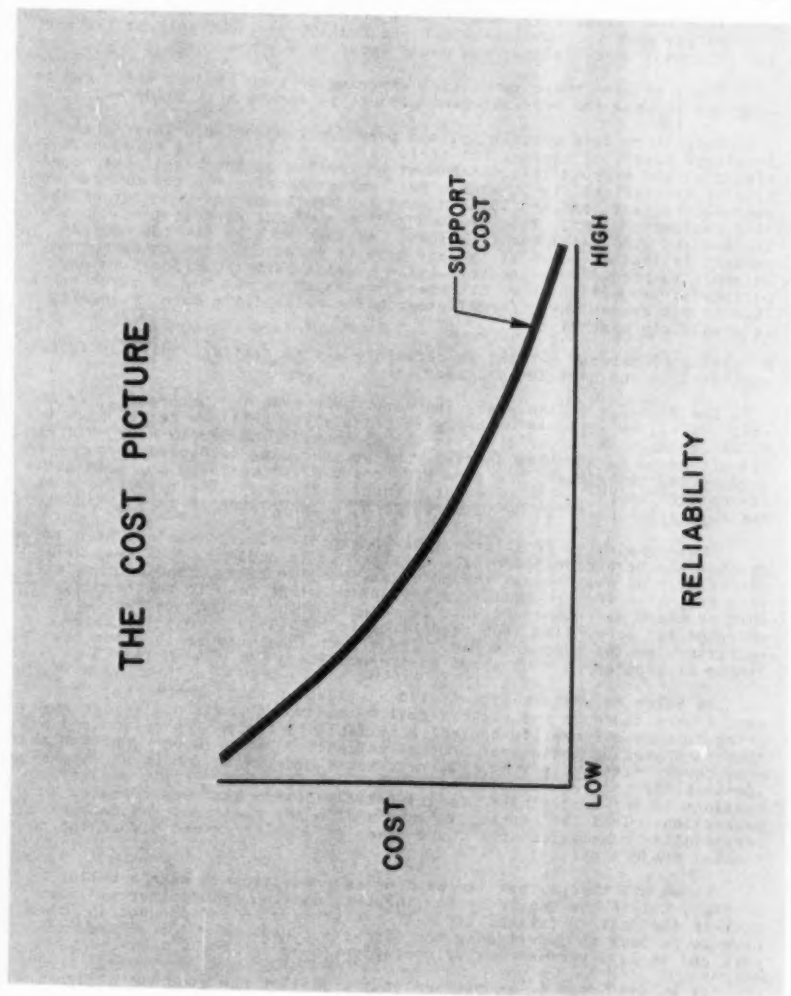
with very low reliability, and it will drop off and approach zero as the reliability goes up. Obviously, if you had 100 per cent reliability and the equipment never failed, you would incur no support cost.

Thus, we have these two curves applying to each project which can be combined to show the over-all cost picture as in the next Slide #4.

Note there is a certain optimum point of compromise. This is an idealized curve, of course, but there is an optimized point between initial cost and support cost which must be reached as the ideal cost objective of the reliability program. But, unfortunately, for the program manager the support cost and initial cost frequently do not come out of the same customer budget. This introduces the need for effective customer liaison and good marketing relations. Another problem for the program manager is that although it is very easy to point out that these curves do apply to projects in general, it is usually rather difficult in any particular project to show just where you stand on any one of these curves. This is one reason why a formal program for reliability data processing is absolutely essential.

B. Timing of Expense -- This is certainly a very critical point as is illustrated in the next few slides.

The tendency in the past, and very often even in the present, is to say: "Well, we will not bother with reliability until we really have to. We are going to keep our costs to the minimum."; and people say: "We cannot afford to do anything special, but we are going to depend on our good engineering techniques, our good production practices, and our good quality control operation to make our product reliable." The result is that the cumulative cost can be illustrated by a curve such as is on Slide #5.

This cumulative cost curve goes up rapidly towards the end when the product has been rejected by the customer as inadequate. The cost definitely goes up well beyond the potential project billing and becomes a very expensive venture including perhaps prestige loss to the company. This approach many times results in returning the product to the factory, redesigning, re-working, and rebuilding it. This is a very expensive operation, so the timing is bad. The effort then must be to bring the timing of expense further ahead on the project.

In Slide #6 we have illustrated a situation where people say "We have a very thorough and capable quality control operation. We are now going to make our quality control a reliability control operation and put them in charge of making our product reliable." This is one approach that many people mistakenly take. It represents bad timing and is an expensive approach for the very simple reason that, in general, quality control operations do not control the product until a design has been released to production. This, of course, is too late in the game, and you can get a very similar cumulative cost curve which can easily extend beyond the potential project billing.

There are things that can be done in production to make a better product, but if the design is bad, quality control cannot inspect-in or test-in the desired reliability. If you achieve an end product and then have to go back to redesigning the circuits, you have a lot of hard rework and it is a very expensive operation.

It should also be emphasized that no matter how good the design inherent reliability may be, the product reliability after production will be low unless you do have good quality control.

These various curves that I have been showing represent common levels of advance in industrial experience. There is this definite trend in each company program development as the people learn from their own experience. It is a human tendency not to be able to learn from others experience, but to repeat one anothers mistakes.

The next Slide #7 illustrates the cumulative cost picture for the next step in the trend toward better product control.

- SLIDE #4 -

- SLIDE #5 -

COST ACCEPTABLE RELIABILITY
PRODUCT ASSURANCE PROGRAM IN PRODUCTION ONLY

- SLIDE #6 -

COST ACCEPTABLE RELIABILITY
PRODUCT ASSURANCE PROGRAM IN LATE DESIGN PHASE

- SLIDE #7 -
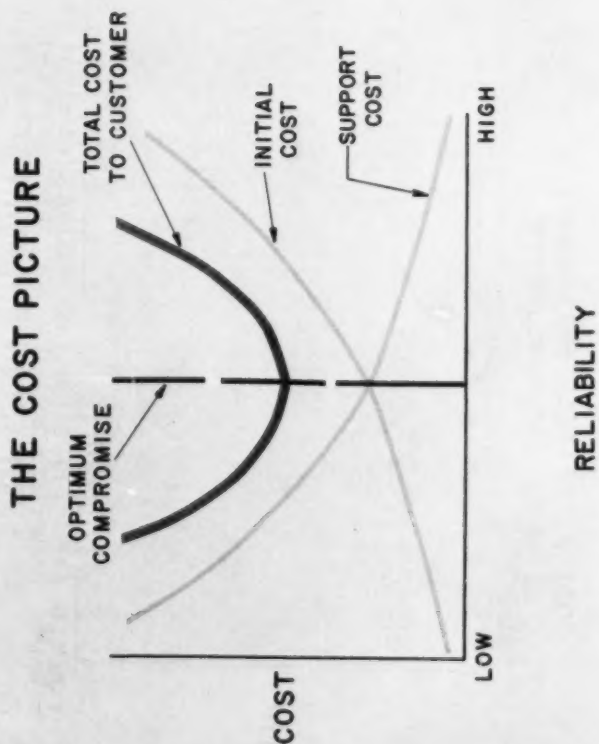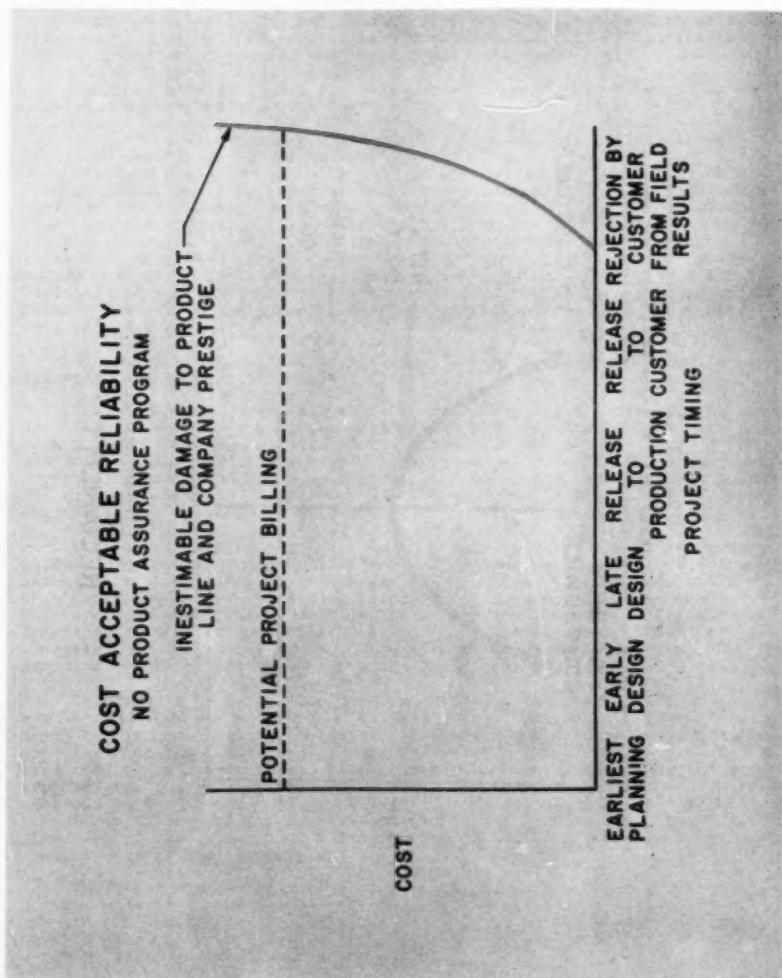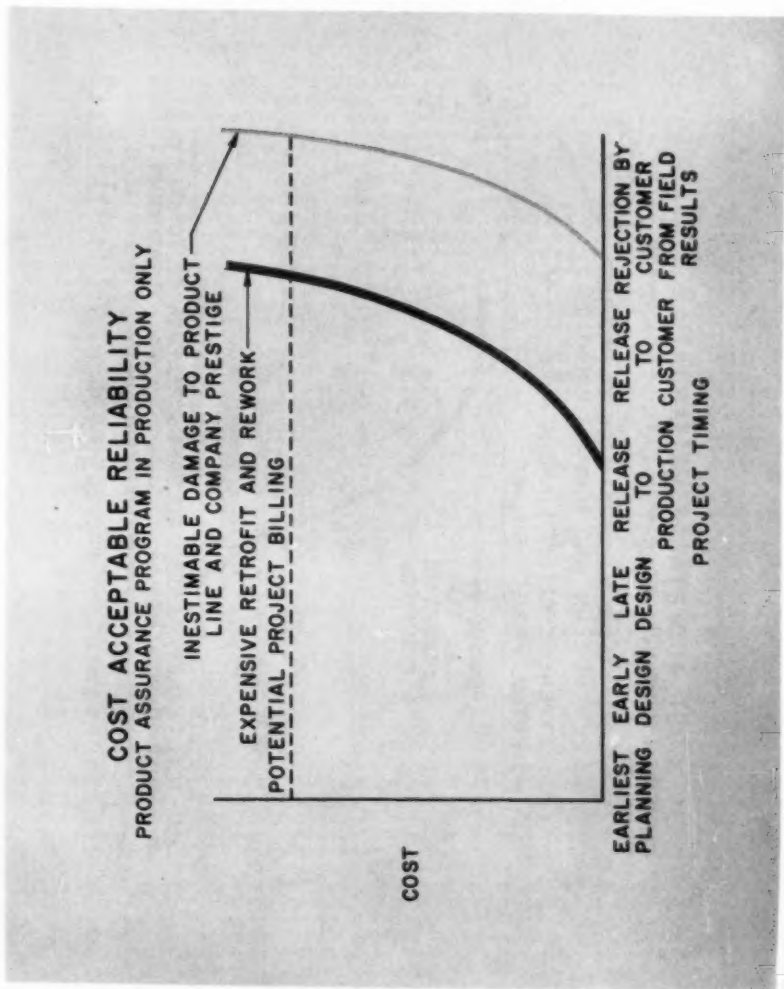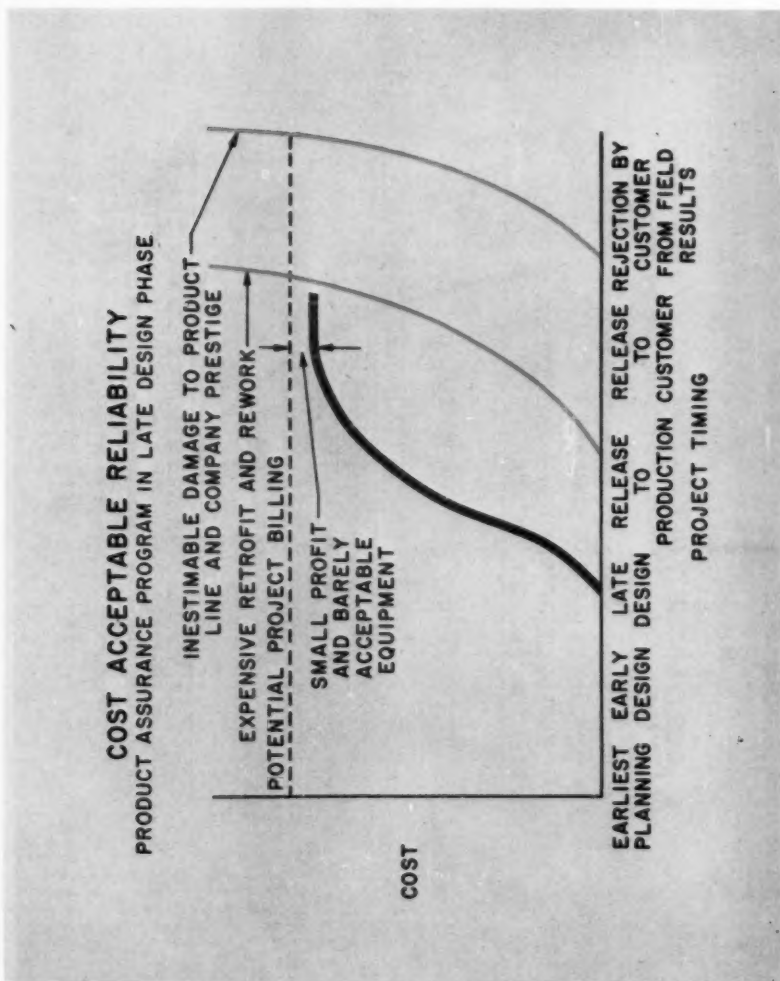
A reliability program is organized to start its activity during late design. The reason for not starting the program sooner is very often because of the engineering tendency to say: "Do not bother me now about reliability. I do not even know what the circuit is going to be yet." The engineers themselves have a tendency to delay the controls this way in spite of efforts by management and other people to push them ahead. You can sometimes arrive at a fairly acceptable equipment this way, but it usually requires some patch-up and redesign. Also, the product is usually not so good as the product which is designed properly from the start in the optimum fashion shown in the next Slide #8.

Here in Slide #8 we have essentially an optimum cost timing curve where you have proper expenses right from the earliest planning of the project all the way through and resulting in the best possible equipment at the lowest possible cost. There are many things that can be said here. For one thing, the curve is not necessarily a flat lineal curve; it might bulge near the start. Actually, the expense early in the game can very often lower the final total cumulative cost. The reason for this is that prevention is usually much less expensive than cleaning up, or correction later on. It eliminates that feedback of defective hardware; it eliminates redesign and all the other rework aspects which mean expense. If the designers are given the reliability responsibility, the control will come after the initial design. Auxiliary services and standards are needed to aid the designers. But, in general, to accomplish this calls for formal organization and we are back to program for reliability control which involves a thorough organization for reliability control in all aspects of the operation.

C. Project Cost Accounting -- The third aspect of cost I want to cover deals with cost accounting procedures. In order to accomplish the optimum expense at the right time, it is essential that the program manager be able to put a finger on things which are not normally accountable in cost procedure methods. The costs that deal with preventive efforts versus fire-fighting and rework for example. These two costs are seldom accounted for separately. The usual cost accounting procedure is established for the simple process of billing to the customer all costs that accrue on his project, and essentially no effort is made to differentiate between preventive expense and corrective expense. This must be done if it is going to be possible to achieve an optimum compromise on timed expense.

The next Slide #9 shows a bar graph of the type needed to illustrate relative costs for control purposes.

Actually, just any single illustration of this nature as shown in Slide #9 set up showing relative costs will not tell the story either. You have to be able to plot this essentially in the time domain showing how the preventive and clean up costs vary from time to time and in accordance with your control efforts. This is a new responsibility of the program manager and is a problem that requires considerable extra effort on every project plus good data control.

D. Value Engineering -- The fourth subject under "doing the job at the lowest cost" is value engineering. This is a program for a second look at every design to make sure that full value is received from every function and device employed in the product. The premise behind value engineering is that value is relative to the usefulness or function served. In no case is value inherent in anything you buy. Value analysis, the tool of value engineering, is the process of comparing relative values.

The problem to the program manager is to achieve more than apparent value. Many alternative methods for accomplishing a function may give essentially the same value until long range reliability support cost is considered. And it is usually very difficult to measure high reliability in a simple enough way to make sure that a supposedly higher value is not causing lower reliability. The present state of the art in reliability requires that value engineering be an integral part of reliability control.

The five major aspects of value engineering important to the program manager are listed on Slide #10. Here are shown the usual four functions

COST ACCEPTABLE RELIABILITY

PRODUCT ASSURANCE PROGRAM FROM START OF PROJECT
WITH ANALYZED OPTIMUM COST

INESTIMABLE DAMAGE TO PRODUCT LINE AND COMPANY PRESTIGE

EXPENSIVE RETROFIT AND REWORK

POTENTIAL PROJECT BILLING

SMALL PROFIT AND BARELY ACCEPTABLE EQUIPMENT

GOOD PROFIT AND GOOD EQUIPMENT

CUMULATIVE COST

A GOOD PRODUCT ASSURANCE PROGRAM FROM START OF PROJECT

EARLIEST PLANNING   EARLY DESIGN   LATE DESIGN   RELEASE TO PRODUCTION   RELEASE TO CUSTOMER   REJECTION BY CUSTOMER FROM FIELD RESULTS

PROJECT TIMING

- SLIDE #8 -

INTER-RELATED COST ITEMS

- SLIDE #9 -
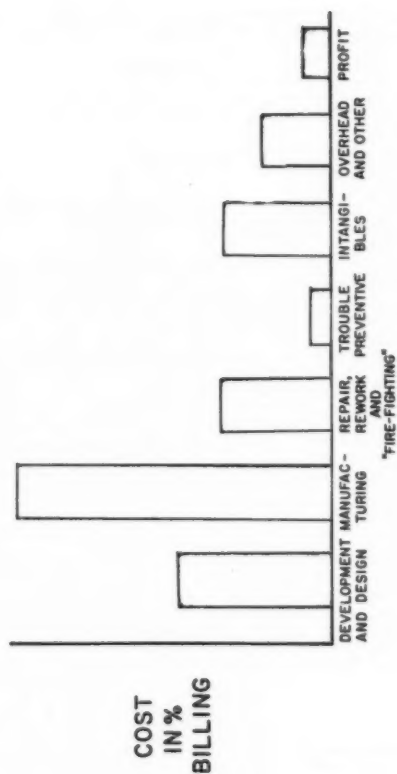
of value engineering plus a fifth which is very important to the program
manager, i.e., "expediting the application of results from value analysis."

<u>LOWEST COST THROUGH VALUE ENGINEERING</u>

1. Getting the facts & item costs
2. Determining the exact function
3. Thinking creatively
4. Evaluating by comparison
5. Expediting application

- Slide #10 -

CONCLUSION

The twenty-one myths in reliability just discussed are only some of
the more common ones. There are many others that might be equally impor-
tant.

In only a few cases has it been possible in the time allowed to do
more than describe the myth. Awareness of what is fact and what is fic-
tion in the new field of reliability is the big job of nearly everyone in
industry and the military today.

I hope this discussion has helped clarify many concepts in your minds
and will stimulate you to further effort in finding answers to the imple-
mentation problems in your areas of work.

ELECTRONIC RELIABILITY - A MECHANICAL PROBLEM

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INTRODUCTION

Many stories in folklore deal with the wide variations between
different interpretations of the same phenomena. Many of these stories
point out the moral that no single interpretation is the only possible
one. Sometimes in electronics work we fail to remember this moral. The
current reliability problem may easily be one result of this failure.

When an electronically-oriented person looks at complex equipment
such as a computor, a guidance system, or a radar set, he is likely to
visualize it first as a system of circuit elements and signals. In the
next step, he will probably consider the nature of these elements and
their electrical characteristics. The mechanical design engineer will
picture a collection of cabinets, racks and chassis and consider how to
hold them in place. The man on the street, of course, sees the same de-
vice as a weird collection of flashing lights, jittery meters, switches,
and - sometimes - long blue sparks. All of these viewpoints are partial-
ly correct; each is limited in some fashion.

This paper will present a mechanically-oriented look at electronic
equipment. The viewpoint, although mechanical, is not limited to the
characteristics generally described as mechanical. A piece of equipment
will be considered as a complex structure serving a structural purpose.
An approach similar to that which might be used in discussing a landing
gear, an airframe, a bridge or a truck's steering mechanism will be
used. The desired result is an appreciation for, and an awakening of
interest in, the possible contributions of a structural approach to
equipment reliability.

Remembering the moral mentioned earlier, we shall refrain from say-
ing that structural integrity is the only criterion for equipment reli-
ability. Electrical characteristics of systems, circuits and components
must be engineered to promote reliable operations. Reliable operation
is impossible, however, when elements of systems, circuits or components
fail structurally. Our basic premise will be the somewhat heretical
statement that most, if not all, electrical equipment failures are the
result of mechanical breakdown.

SYSTEMS

A large electronic equipment is a complex system of electrical parts
and circuits. It is also much more than that. When you adopt a mechan-
ical viewpoint you see a complicated non-homogeneous structure rivaling
the largest mechanical structure in its complexity. In a typical system
you find soldered and welded joints, roller joints, pin and rivet joints,
friction joints and bolted joints. There are cantilever, simple and
continuous beams arranged singly and in odd shaped trusses. A variety
of tension, compression, shear, torsion and bending loads are applied
impulsively, steadily, dynamically and repetitively. Interacting ele-
ments are coupled statically and dynamically. Although few parts are
designed to be moving parts, many sections are effectively moving parts
with small excursion because of deflections and deformations. Under the
right conditions any part of this system can fail as a mechanical struct-
ure. When this happens, the system will usually fail as an electrical
structure as well. The next few paragraphs will explore some conditions
which promote electrical failure as a secondary effect of a primary
mechanical failure.

HUMAN FACTORS

The human element enters the system at the first fabrication stage. The best assemblers in the world will occasionally forget how to do some part of a job or they will misinterpret their instructions. Operations will be missed or done incorrectly under the best conditions; if conditions are not the best, errors will be even more common. Every quality control investigator has had the experience of looking at a defective piece with the feeling that the assembler must have gone completely insane to make it that way. Unfortunately every assembly error is not in this class. All too frequently we find a design or a process sheet which seems to require a combination of Superman and a magician to figure it out, let alone put together. A previous paper (1) listed some points which should be considered to avoid this unpleasant situation. By their very nature these points may be skipped in the design stage. They are the mechanical design details which change a design from something to fight in production to something which is a joy to build. The main reason they are overlooked is that they are obvious - after they are mentioned. For example, everybody knows that you must be able to see a terminal if you are going to do a neat soldering job on it, that pushing a wire aside to reach a mounting screw is potentially a source of broken wires, and that reversed cables usually cause trouble. Designs are still made every day with these faults and many others designed into the system.

System maintainability and operability have received considerable attention in the design stage during the past few years. The effects of both on system reliability in service have been explored extensively, and checklists of good practice have been developed. The areas of assembly and handling have not received the same degree of specialized attention.

Correlation between an impulsive load applied when a chassis is dropped on the loading dock, or even when an access door is slammed shut, and electrical failure may be difficult. Correlation between the same load and a fractured component is relatively easy. In between these two levels is the situation where the impulsive load shifts a component slightly in its mounting thus putting extra stress on the component leads. Snapping a diode into a clip, bending a lead at the surface of a glass header or warping the mounting flange of a relay slightly during installation may not cause visible damage or obvious malfunction. Internal stresses and deformations are set up which eventually will lower the ability of the part to withstand additional loads.

Although we all pride ourselves on the ability and skill of our production people, perhaps the safest course during the design stage is to assume that they are all illiterate dunderheads waiting for the chance to do something the wrong way. Our designs and processes should, whenever practical, preclude a failure due to sloppy workmanship.

ENVIRONMENTS

A system must operate and survive in a series of environments. These environments consist of all natural and artificial phenomena in the system's immediate vicinity. In addition to standard environments such as vibration, shock, atmospheric pressure and temperature, moisture and corrosive atmospheres, we might consider time and gravitational attraction as well. Space systems programs have become aware of the effects of low gravity, but most of us still take gravity for granted. Gravitational attraction exerts an appreciable force on all parts of our systems; these forces must be reacted within the system, and hence stresses are introduced. Time, or duration, is an important environment in that chemical processes and cumulative effects are affected. No real substance is completely inert with respect to duration. Changes take place in systems which can only be explained and studied by considering duration as an environment.

The engineer must realize from the start that he can not eliminate the environment. The best he can hope to do is protect the system from harmful environmental effects. Because most environmental effects act through mechanical means, protection is almost invariably mechanical.

Shock mounts, vibration isolators, thermal barriers and adequate struc-
tural strength are all means to prevent overstressing electrical parts.

STRUCTURE

A system consists of two basic types of members. The active ele-
ments are electrical components while the passive elements are primary
structure such as racks, cabinets, chassis and other framework. It is
characteristic of much of our modern electronics equipment that a thou-
sand dollars worth of electrical system is wrapped up in ten dollars
worth of sheet metal. A program which allows two years to develop a
system will spend two weeks in developing primary structure. In some
cases more attention is given to markings on the front panel than is
given to the strength, rigidity and durability of main equipment support.

Primary structure must do more than merely hold the system togethen.
The primary structure transmits all external environmental loads, and
provides most of the protection against these loads. Improper design can
provide transmissibilities and force magnifications orders of magnitude
greater than those found in a good design. Energy received from both
external and internal environments must be dissipated. If this is not
accomplished in the structure, it must be done within the active ele-
ments. Structural design must be a series of compromises between ade-
quate protection and excessive weight and cost. A cartoon widely circu-
lated in aircraft design sections shows the "ideal" airplane as envision-
ed by each design section. In this cartoon, the structures section's
airplane consists of massive I-beams riveted together with gusset plates
and braced with chain. Such an approach is as unrealistic for electronics
as it is for airframes. The opposite extreme with thin members, flimsy
hinges, and large flexible panels is equally unrealistic.

COMPONENTS

Many system failures are caused by failure of some critical elec-
trical component. Tubes become noisy, resistors change value, diodes
open up, relays stick, and transformers develop shorted windings. These
failures, and a host of others, are mechanical failures rather than elec-
trical. In fact, with the exception of some types of semiconductor
failures, all component failures are mechanical in nature although the
end result is an electrical failure.

The logic behind this statement becomes evident when the internal
structure of electrical components is made the area of interest instead
of the purpose of the component. For example, the purpose of a tube is
essentially either rectification, amplification or controlling a signal.
How well the tube serves its purpose is dependent on the mechanical
characteristics of envelope integrity, element continuity, element spac-
ing, cathode coating uniformity, and foreign particle content. Assuming
that the correct tube type was chosen for the circuit application, cir-
cuit performance is dependent only on these mechanical features. The
standard descriptions of tube failure, e.g. low gain, noisy, intermittent
operation, are really descriptions of symptoms. The actual failure of
the tube is the failure of the tube structure. True tube failures would
include element displacement, broken element or lead, abraded spacer,
defective seal, and flaked cathode coating.

This discussion would be academic - even pedantic - were it not for
the insight such an approach gives to the relationship between applied
loads and component failures. Loads applied to the component structure
generate mechanical stresses in the structure. If these stresses exceed
the strength of the structure, the component fails. The means by which
the loads are applied may be electrical, e.g. current surge, thermal
e.g. high ambient temperature, or mechanical, e.g. shock, without obscur-
ing the relationship.

Since the objective of reliability programs should be the reduction
or elimination of equipment failures, this relationship should be ex-
plored more fully.

COMPARTMENTED DESIGN

In the introductory remarks reference was made to some of the different viewpoints possible in visualizing an electrical system. There has been a movement in recent years to capitalize on this by processing a new design through various stages of design review and redesign by different segments of the organization. New designs are scrutinized, modified or approved by disinterested designers, reliability engineers, value analysis committees, field service engineers and a host of others. Almost every conceivable combination and permutation has been tried at least once. When properly done, this process can assist in developing a device that actually works in service as well as it did on paper. A recent paper (2) discussed design reviews in general and some effective types of review programs. As long as design review does not result in a "compartmented" effort, the idea is sound. If design reviews or similar programs develop a series of independent designs tacked together rather than a single integrated design, they will defeat their own purpose.

In a hypothetical, but all too possible, program we might find a design passing successively through complete redesigns in which each section has followed its own particular bias without respect for previous work. By the time the circuit designer, applications engineer, mechanical features engineer, packaging engineer, reliability engineer, maintainability engineer, producibility engineer, value analysis section, cost reduction committee, field service technician, inspection processing engineer, weight control analyst, tooling engineer, and all the rest have each taken a stab at "improving the product", the end item will look like a patchwork quilt. Any resemblence to the original design is purely coincidental.

This paper does not advocate a compartmented approach. Consideration of mechanical characteristics must be as much a part of the designers' original work as determination of voltage levels and waveshapes. An electronic system designer has as little right to say that fatigue life of a tube spacer is not his concern as a hydraulic system designer has to disregard the bursting stress of a piece of tubing. Should the objection be raised that specialization is necessary in modern industry, the only answer is that a designer must not be so specialized that he can not design properly. We do not expect a system designer to be a specialist in inductance and be completely ignorant of capacitance. Why then should we accept the idea that this designer may legitimately claim to be a specialist in electrical characteristics and ignorant of bending stresses?

Consideration of mechanical aspects of electrical designs must be as basic to system and circuit designers as electrical aspects. Quality control, reliability, manufacturing, processing and other sections must expand their fields of interest beyond those required for purely electrical considerations. None should fall into the trap of treating each consideration purely as a separate entity. Any review or study of the mechanical side of a design should be integrated with the electrical side. This applies equally to study of production problems, service failures and original designs.

RELIABILITY DEFINITION AND PREDICTION

Reliability is generally defined, at least in Reliability circles, as "the probability that the device will perform its intended function". The phrases "for the intended period" and "when used in the intended manner" are usually added, but these are tautological. Using this definition, reliability requirements have been specified, predictions have been made, and equipment has been redesigned or scrapped. The definition is useful in establishing a figure of merit for a device, but is not very helpful in designing or building anything.

For discussion purposes, a new definition for "reliability" is proposed:

"The reliability of a device is the probability that applied loads will not cause stresses in an element of the device to

exceed the failures strength of the element."

This definition is based on four fundamental ideas:

(1) An element or a device has failed when it ceases to perform
     the function for which it was intended.

(2) A device fails if, and only if, some element of the device
     fails.

(3) An element fails if, and only if, a particular stress or set
     of stresses exceeds the strength of that element.

(4) A stress is induced in an element if, and only if, a load is
     applied to the element.

Under these conditions the probability of no failure is obtained
automatically from consideration of applied loads and element properties.
Since, as we have seen, time is simply another type of load application,
the time factor in the "classical" reliability definition is included.

If we use this proposed definition, we have a means of studying
and improving the reliability of systems and components. The definition
focusses attention on basic questions regarding failure:

            (1) What are the expected loads?
            (2) What stresses will these loads generate?
            (3) What is the strength of the piece?

Testing and analysis of systems, environments and properties can
provide, within acceptable engineering accuracy, these answers. Natur-
ally both loads and strengths will have statistical distributions; cal-
culation of probabilities under these conditions is routine.

Reliability analysis then becomes a question of straight engineer-
ing similar to that used in the design of reliable systems such as
bridges, skyscrapers, airframes and steam engines. Each element in a
system can be investigated, either analytically or by experiment, to
determine what loads it must carry, how the loads will be applied, and
what will be the results of applying these loads. For example, let us
consider a resistor used in an application where resistance must not
vary appreciably. To compute the reliability of the resistor, we might
follow these steps:

        (1) Question: Why does resistance vary?
             Answer : Properties change with heat.

        (2) Question: What heats a resistor?
             Answer : (a) Heat from surrounding environment,
                        (b) Internal heat generated by passage of
                            current through a resistance.

        (3) Question: What current variation can we expect?
             Answer : Derive from circuit analysis and measurement.

        (4) Question: How does the resistance value vary with heat?
             Answer : Plot ohmeter readings vs. thermocouple read-
                        ings.

        (5) Question: What is a failure?
             Answer : Resistance value outside specified limits.
                        Therefore heat outside computed limit.
                        Therefore current outside computed limit.

        (6) Question: What is the reliability of this resistor in
                        this application?
             Answer : Compute from results of steps (3) and (5).

Since this was an example intended only to outline an approach, it
was somewhat over-simplified. Other factors, such as variation of pro-
perties with time and non-homogeneity of resistors could be included if
desired.

The classical definition of reliability can be used to set goals and measure accomplishments. It can not be used to predict what you will achieve for new designs or to tell you how to take corrective steps. The proposed definition and study of mechanical factors overcome both of these objections.

CONCLUDING REMARKS

The ideas presented in this paper are not necessarily new. In fact most of them are as old as engineering itself. In a dynamic culture, old ideas are sometimes overshadowed by new ones or they are forgotten in our enthusiasm for moving ahead. The idea that an electrical part is a mechanically stressed member as well as a functional circuit element may be new to some and old to others. If this paper provides the impetus for designers, quality engineers and reliability specialists to consider failures from a different perspective it will have served its purpose.

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OPTIMIZATION OF EQUIPMENT EFFECTIVENESS

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In the many fields of responsible manufacturing, an endeavor to pro-
vide "Product Value" may be recognized as a common pursuit. The precise
image of this ideal and the methods used to attain it will vary with the
product, and will become more difficult to define as the complexity of
the product increases -- clearly, value criteria may be determined and
value goals achieved more easily in the manufacture of garbage cans than
of airliners. At the summit of such an hierarchy, the problems of
trading-off performance with cost become acute when military usage intro-
duces possible cataclysmic consequences of failure or error.

Under Air Force auspices, ARINC Research Corporation has been en-
gaged in a program directed towards developing techniques for gaining
maximum product value in the specific area of airborne electronic equip-
ment. This is an extensive project, the scope of which is illustrated to
some degree by Figure 1, which shows ARINC's concepts of the factors
which must be considered in a study of equipment value.
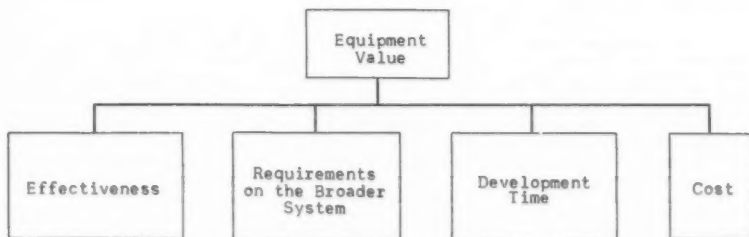
FIGURE 1

FACTORS AFFECTING EQUIPMENT VALUE

"Effectiveness" is a measure of the equipment's ability to fulfill
the requirements of the job for which it is purchased. The second
factor -- "Requirements on the Broader System" -- encompasses equipment
characteristics such as weight, volume, power requirements, which tax the
supporting environment. "Development Time" is included since, in the
consumer products field, its careful control may well enhance the value
of a product by allowing its marketing ahead of the product of a competi-
tor; a short Development Time for a military equipment may be the essence
of its value to the defense structure of the Nation. The "Cost" factor
included in this breakdown may be considered purely in terms of the dol-
lars and cents expended in initial costs and subsequent upkeep, although
it is conceivable that, for military equipments, it may sometime become
necessary to extend the concept of cost to include such other items, per-
haps, as a raw material in short supply or human life itself. All these
factors must be weighed and judicious compromise applied in order to
achieve a design leading to the best equipment value for the circum-
stances.

The provision of methods for predicting the trade-off relationships
which will facilitate such compromising is a long-term aim of ARINC's
project. In this pursuit, techniques for quantifying, measuring, and
fully understanding the elements of the four factors affecting equipment
value must be developed. Information obtained by the application of such
techniques to existing equipments must then be used in turn to develop
methods of synthesizing values for these factors for new equipments while
they are still in the conceptual and early-design stage. Several such
estimates or predictions computed for each factor with different condi-
tional values assigned to the other factors, will provide the trade-off
functions upon which the early policy and design decisions may be based.

Of course, when working towards an ultimate goal of equipment value
maximization, it does not suffice to provide only a capability of pre-
dicting the contribution of each factor. Attention must be given also to
developing methods of optimizing the contributions themselves. In the
area of Effectiveness, where most of the work to date has been concen-
trated, studies directed towards attaining these two ends are very
closely interwoven and have proceeded concurrently. Figure 2 is a sim-
plification of the framework within which the study of Effectiveness,
from both viewpoints, is progressing at ARINC.

The breakdown shown provides two channels of research -- Design
Adequacy and Mission Reliability-Operational Readiness. Without going
into precise definitions, the former concerns the equipment's ability to
do its job if working correctly; the other, the probability that it will
work correctly when required and the probability that it will work for a
given time. In Figure 2, the detailed analysis afforded the latter chan-
nel, while Design Adequacy remains singularly uncomplicated, suggests
that research effort in the realm of quantification and prediction tech-
niques has not been equally divided between the two. This is true, and
this circumstance, rather than any wish to belittle the importance of
Design Adequacy, explains the orientation of the remainder of this paper
toward our studies of the Mission Reliability-Operational Readiness as-
pect of Effectiveness and, specifically, its essential components: reli-
ability and maintainability.

At this level, the tactical approach to ultimate value maximization
has been the development of techniques for reliability and maintainabil-
ity prediction. Such techniques not only will aid in providing the
initial predictions mentioned previously, but also will play an important
role in the optimizing of reliability and maintainability (and thereby,
effectiveness) during the design, prototype and testing phases of an
equipment's development. During this time, periodic predictions of field
reliability and maintainability, based upon the constantly changing data
from drawings, part and unit tests, system tests, etc., will disclose
with what proximity the desired field levels for these characteristics
are being approached, and in what areas design improvement effort should
be concentrated. Although the future tense has been used here, it will,
of course, be realized that the use of reliability prediction techniques
developed to date is already widely recognized, particularly for the
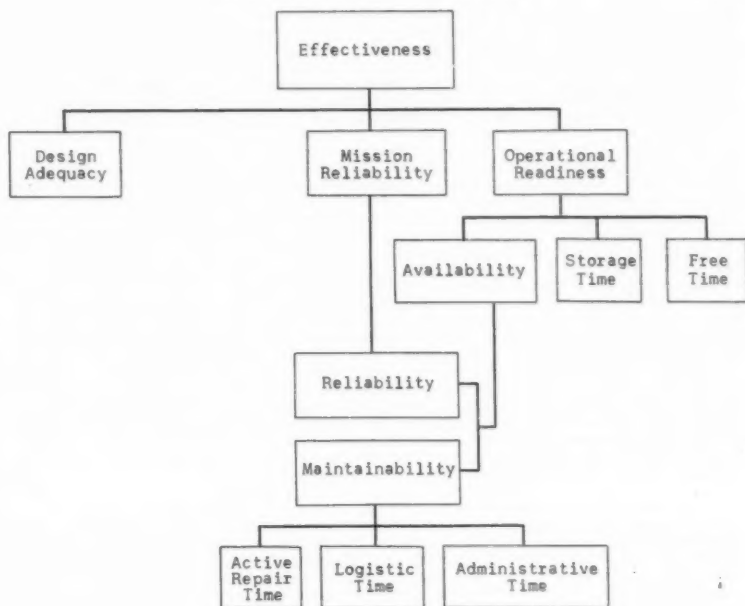
FIGURE 2

CONCEPTS ASSOCIATED WITH EQUIPMENT EFFECTIVENESS

design-improvement purpose mentioned above. The time is at hand, more-over, when documented prediction of reliability is being specified as part of military acceptance procedures, bringing closer the day when such assurances will be required at the over-all Value level. In this connec-tion, it must be realized that as equipments become more complex and potential use environments become more difficult to simulate, ultimate performance and value become increasingly difficult to estimate without some such detailed prediction method.

The foregoing discussion having placed the roles of reliability and maintainability prediction studies in proper perspective within the long-term plans for Value maximization, we will proceed to a detailed discus-sion of these studies. The mention of reliability prediction's current use and anticipated further use illustrates that studies in this area are well ahead of those in the maintainability field. Reliability prediction in practice is well established -- even if not in all cases well under-stood -- while maintainability prediction is still a curiosity. For this reason, rather than reiterate in extenso the details of reliability pre-diction methods, we will merely recall the basic approach and a particu-lar ramification thereof, and provide a fuller treatment of our work to date on maintainability prediction.

In essence, reliability prediction during equipment design and devel-opment is achieved by the summation of established part failure rates applied to every part in the equipment. The total failure rate so

obtained can be converted by use of the exponential equation to the pro-
bability of successful operation for a given time or, more popularly, to
an MTBF. A serious problem concerning the interpretation of these pre-
dictions arises at their very root, due to the many types of "established"
failure rates being used and the varied treatments they receive. ARINC's
prediction method uses rates derived from our own extensive field surveil-
lance of military equipment. Generally speaking, all removals to effect
a repair are counted as failures and included in ARINC's failure-rate
computations. At the point of final summation, correction is made for
"cluster" removals and an inclusive rate is inserted to account for re-
pairs made by adjustment. Final corrections are made to account for the
complaint-repair differential. Another procedure, however, discounts all
but catastrophic failures in deriving the part failure rates and making
predictions therewith. In addition there are failure rates generated by
part manufacturers and equipment manufacturers under all kinds of physi-
cal conditions and criteria of failure. No quarrel is found with the use
of any of these rates and procedures so long as the resultant predictions
are not misinterpreted. For instance, a procedure which predicts only
malfunctions due to catastrophic failures will not predict field reliabil-
ity accurately; malfunctions due to deterioration, need for adjustment,
or other aspects of what is labeled ineffectual maintenance, will not be
included. This procedure will predict, however, the reliability supplied
by the manufacturer when influences beyond his control are not considered.
On the other hand, the failure rates and technique used by ARINC will
build into a prediction an accounting for field influences, and by so
doing will best predict field reliability. The point to be made is that
a reliability prediction is of little value without information on the
failure rates and procedure by which it was generated.

An interesting illustration of the type of circumstance which as-
sures discrepancy between the two types of prediction just referred to,
also provides an excellent transition to maintainability discussion, in-
asmuch as it establishes that maintainability not only has its direct
influence on availability but has a secondary influence by way of its
effect upon reliability. During ARINC's current surveillance of an Air
Force Bomb/Nav system, it has been observed that the majority of mal-
functions occur during the first one tenth of a mission's flight time --
in fact, a large part occur immediately at take-off. It is ARINC's con-
tention that this higher rate of malfunction early in flight is not
caused by take-off stresses as might facilely be concluded, but rather by
malfunctions which actually occurred during previous in-flight or ground
operation and which were not corrected by maintenance. This explanation
is supported by evidence supplied by two conditional probabilities de-
rived from the observed data.

The probabilities are defined as follows:

(1) $P(S|S_p)$

   The probability of successful flight (no in-flight malfunction),
   given that there was no malfunction on the preceding flight and
   therefore no corrective maintenance action between flights.

(2) $P(S|M_p)$

   The probability of successful flight, given that there was a
   malfunction on the preceding flight and therefore there was a
   corrective maintenance action between flights.

On the basis of data collected over a twelve-month period, computa-
tions of the two conditional probabilities disclosed that the MTBF under
the first condition was 34% higher than that under the second condition.
Clearly, the probability of a successful flight is lower if a malfunction
occurred on the preceding flight. The consistency of this relationship
throughout the whole twelve months represented lends authority to the
conclusion.

This ever-present aspect of imperfect maintenance is accounted for in the prediction technique developed and used by ARINC. Such a prediction for this equipment would estimate a probability of successful flight within the limits of the two conditional probabilities referred to above, while a prediction which, by the nature of its basic inputs, was restricted to estimating the unreliability due only to catastrophic part failures would provide an estimate well above the more optimistic of the two probabilities.

The imperfection in maintenance illustrated above is not necessarily the fault of maintenance personnel, but often is the result of maintainability problems beyond their control. It is difficult, for instance, to repair a malfunction whose symptoms cannot be observed in the ground environment. Maintainability, then, not only concerns the time required to correct a malfunction, but also the probability that the malfunction can be observed and recognized by maintenance personnel. It is the time aspect, however, which must be the subject of maintainability prediction techniques; consideration of the latter symptom observation must perforce be included in the reliability prediction. Work on the development of maintainability prediction techniques has proceeded at ARINC along a line similar to that used for reliability prediction. The maintenance activities on a group of Air Force Bomb/Nav systems in field use have been under observation for approximately one year. The purpose of this surveillance is to accumulate data which will provide the basis for description of the relationships between physical and circumstantial characteristics, and the length of time required to perform elemental activities germane to system maintenance in the three broad areas of

> (1) Administrative Time (inactive Down-Time)
>
> (2) Logistic Time
>
> (3) Active Repair Time

The data will also be used to establish the probability that each such elemental activity will occur as part of a period of system "down time". For the system under observation, the lowest level which can be considered is the unit, since almost no system maintenance is performed below that level. Similar relationships for parts must be established from other surveillance activities for systems which are maintained at the part level. The physical and circumstantial characteristics which seem reasonable items to be considered with reference to a unit are weight, volume, aspect ratio, number of visible or audible outputs and the like. Possibly more complex and seemingly unlikely are the characteristics which must be considered as influencing Logistic Time and activities of Administrative Time. The elemental activities referred to are a list of some 100 activities associated with Administrative Time and with Active Repair Time grouped into the following six categories:

> (1) preparation
>
> (2) symptom verification
>
> (3) fault location
>
> (4) part procurement
>
> (5) repair
>
> (6) final test.

Logistic Time is not subdivided into elemental activities, but is treated as an elemental activity itself.

The first major analysis of data will be made in the near future, since sufficient observations have been collected to generate many hundreds of equations of the following model:

$$t = a_0 + a_1x_1 + a_2x_2 + a_3x_3 \ldots\ldots a_nx_n$$

where t = time required to perform the particular elemental activity in this observation.

$x_{1..n}$ = values quantifying physical or circumstantial characteristics of the unit or activity involved in this observation.

$a_{1..n}$ = unknown factors representing the relative influence of $x_{1..n}$ on t.

a_0 = unknown constant.

The equations will be grouped by elemental activity and, assuming that the hypotheses underlying regression analysis are satisfied, regression analysis will be programmed on a computer for each group to obtain estimates of the regression coefficients ($a_{0..n}$) and the standard error of estimate. A characteristic whose regression coefficient for a particular elemental activity is not significantly different from zero may be considered to have no bearing on that activity and dismissed from the equation. The estimates of $a_{0..n}$ remaining for each elemental activity can then be used in the same model to predict the distribution of times required to perform this activity for a new system. The values for $x_{1..n}$ will be obtained from specifications or knowledge of each unit, part or activity of interest.

It will have been recognized, perhaps, that a very difficult problem is faced in conceiving and quantifying all the pertinent items symbolized by $x_{1..n}$. If this endeavor meets with success, however, knowledge of all the physical and circumstantial characteristics to be built into or to provide environment for a new system will permit prediction of (1) a distribution of times for Logistic delay, (2) a distribution of times for performance of each one of the elemental activities of Administrative Time, and (3) a distribution of times for each one of the elemental activities of Active Repair Time as applicable to each unit or part (or classified grouping of units or parts) of the system. At this point the problem is reduced to one of combining these basic distributions in such a manner as to provide an accurate prediction of the over-all distribution of times required to repair the system.

Assuming that the times required to perform the elemental activities are independent of each other, an adequate solution to the combinatorial problem apoears to be provided by employment of a Monte Carlo technique. Any number of discreet values representing the time required to complete a total maintenance action can be synthesized for the new system by this technique. The synthesis involves the use of the basic predicted distributions of times required to perform the elemental activities, and a distribution-selection discipline imposed by the probability of failure for each unit (or part) and the probability of occurrence of each elemental activity (the former probability is derived from a reliability prediction; the latter, by analysis of the new system and reference to past experience). The distribution of times so synthesized will constitute the predicted distribution of total system maintenance times. Gratifying results have been obtained so far from exercises designed to test the efficacy of such application of Monte Carlo methods.

Such is our theoretical and practical approach to developing a method of predicting maintainability. As studies progress, it may become evident that the characteristics controlling some time patterns are too intangible to define or quantify, in which case compromises with perfection must be endured. On the other hand, it may be determined that other time requirements will remain unchanged in association with any system, at any time, in any place. In such cases, prediction is reduced to its simplest terms.

Reliability prediction is here; maintainability prediction is not far behind. With these two capabilities available, studies in the Mission Reliability-Operational Readiness area will approach fruition. Design Adequacy must then receive full attention in order to fulfill the aim of Effectiveness prediction and optimization. Of the four factors affecting Equipment Value, Effectiveness is considered to offer the greatest and most time-consuming problems to be solved. The other three factors are believed to be more receptive to treatment by adaptations of established methods and, hence, the road to Value prediction and maximization will be considerably more than one quarter covered when Effectiveness studies are completed.
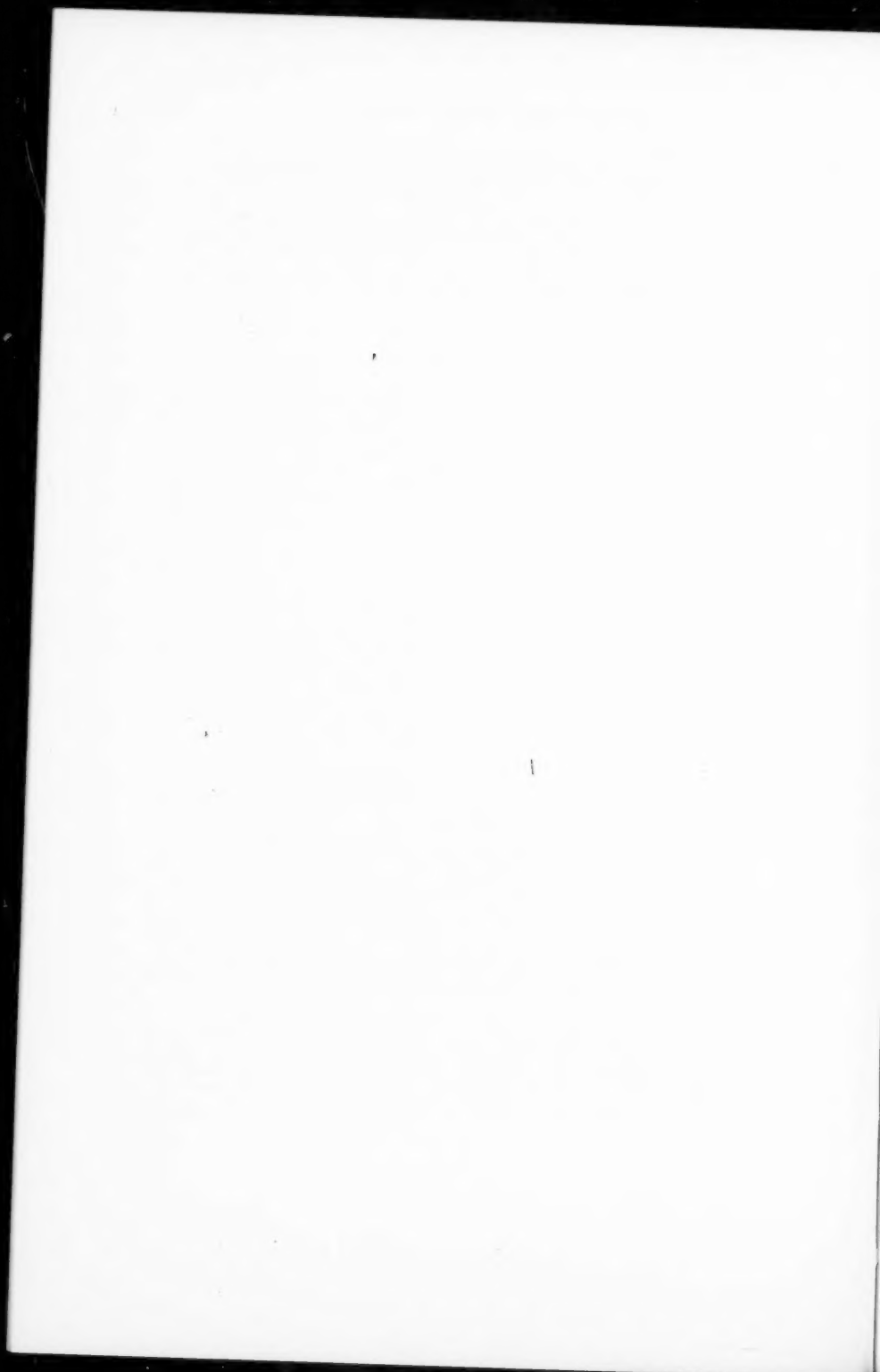
COMPUTING EQUIPMENT USED FOR
STATISTICAL STUDIES IN THE METALS INDUSTRY

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This paper is a report on a survey conducted by the Metals Technical Committee of the American Society for Quality Control to ascertain the types of computing equipment available to individual members of the Committee and the types of equipment which would be used by them in processing data for several specific statistical methods.

BACKGROUND

The interest of the Metals Technical Committee in the use of computing equipment is evidenced by the convention papers concerning the use of such equipment sponsored by the Committee since 1953 (references 1, 2, and 4 to 11 inclusive).

The use of the survey procedure to develop information within the Metals Technical Committee was first employed in 1953 with reference to statistical methods used in the metals industry. The results of that survey were reported at the 1954 convention (reference 3). The survey results being reported in this paper were collected along similar lines to those employed in the 1953 survey.

SURVEY RESULTS

A questionnaire, example attached as Exhibit I, was sent to the 110 names which appeared on the Metals Technical Committee mailing list as of February 5, 1960. Replies were received from 76 members of the committee; these replies are the basis of this report.

All of the replies received have been summarized in Exhibit II. Equipment category I was for "other equipment" such as X-Y plotters and analog computers. The only item reported which could not be described by one of these examples was the abacus.

The most frequently received reply for each method, for each degree of urgency, and for each data volume has been summarized in Exhibit III.

BIAS

In drawing conclusions from the data, the following conditions should be kept in mind:

    a) The 76 replies contain differences in interpretation of the questionnaire so that there is no assurance that all of the replies are answers to the same questions.

    b) The population sampled was the membership of the Metals Technical Committee which membership is not necessarily a representative sample of the quality control personnel of the metals industry or industry in general.

SUMMARY

The data obtained on the availability of data processing equipment indicates that most of the repliers had a desk calculator immediately available. About half of the repliers had a medium scale electronic computer available within the plant. Large scale equipment when available is located outside the plant at the corporation or service bureau level.

The degree of availability of the various types of equipment obviously influenced the choice of the particular types of equipment to be used in the solution of the various statistical problems presented in the remainder of the questionnaire. The replies received, however, indicate that most problems, even those of complex nature, are still being solved with relatively simple equipment when adequate time is available.

LCS 730:90:433

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10. Morreale, M. V., "I.B.M. Data Processing Equipment as Applied to Quality Control," National Convention Transactions, 1959, pp. 659-662.

11. Smiley, J. H., "Suggestions for the Contributions that the Data Plotter May Make to the Implementing of Modern Data Processing Techniques to Statistical Quality Control," National Convention Transactions, 1959, pp. 689-695.

EXHIBIT I

Metals Technical Committee - American Society for Quality Control

SURVEY OF EQUIPMENT USED TO PROCESS DATA
IN STUDIES EMPLOYING STATISTICAL METHODS

Questionnaire

1. Authority. The Metals Technical Committee of the American Society for Quality Control authorized this survey in Pittsburgh on February 5, 1960.

2. Purpose.
a) To collect information on the types of equipment available to individual members of the Metals Technical Committee for the processing of data in their statistical studies.

b) To determine the types of data processing equipment used in processing data for several specific statistical methods.

c) To prepare a summary of the information collected for presentation before the membership of the Society at its 1961 National Convention. The identification of individual contributors will not be revealed in this summary.

3. Coordinating Task Force.

        F. G. Norris   - Metallurgical Engineer - Statistics
                    Wheeling Steel Corporation
                    Steubenville, Ohio

        D. H. W. Allan - Metallurgical Statistical Analyst
                    American Iron and Steel Institute
                    150 East Forty-Second Street
                    New York 17, New York

4. Participants. The participants in this survey are restricted to those members of the Metals Technical Committee of A.S.Q.C. who voluntarily submit data.

5. Equipment to be Surveyed.
a) In order to develop information regarding the data processing equipment available to the individual members, page A of the attached questionnaire has been prepared.

b) The equipment has been categorized into seven basic groups as shown below. These groups have been defined by reference where possible to IBM equipment for convenience of comparison purposes only. These references do not restrict the participants to that particular manufacturer's equipment.

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	--
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	--
F	Calculating punch	IBM 602, IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers

In addition, a category X has been provided for the situation where the answer might be "would not attempt within limitations of time and available equipment."

c) Information regarding the present availability of the above equipment to each member has been requested on page A of the questionnaire attached. The availability has been categorized at five levels as shown below:

EXHIBIT I (continued)

Category   Description

   I   Not presently available
   II   Immediately available
   III   Available on request within plant
   IV   Available on request within corporation outside plant
   V   Available on request outside the corporation on a service bureau basis

d) Information regarding the availability of programming for the various statis-
tical methods also has been requested on page A of the questionnaire by use of
the following three categories:

              a. No prepared programs available
              b. A few basic programs available
              c. Most programs required available

e) Information regarding the sources of programming for the various statistical
methods also has been requested on page A of the questionnaire by the use of the
following four categories:

              d. Write own
              e. Manufacturer
              f. Users' group
              g. Personal contacts

6. Statistical Methods to be Surveyed.
    a) In order to determine the types of the data processing equipment which the
individual members use customarily in processing data for several specific sta-
tistical methods, pages B, C, and D of the attached questionnaire have been
prepared.

    b) The statistical methods have been categorized into three main groups, namely:

              1. Distribution Statistics
              2. Correlation and Regression
               3. Analysis of Variance

Each group contains a number of specifically identified statistical methods for
which information is required.

    c) The participant is requested to indicate which of the presently available
equipment categories is or would be used, if required, for problems of specific
magnitudes each with definite degrees of urgency. The degrees of urgency are
as follows:

          I   Answer required in 1 day (immediately)
          II   Answer required in 7 days (fairly soon)
          III Answer required in 30 days (no hurry)

    d) The principal equipment which is or would be used, if required, for each situ-
ation on pages B, C, and D of the questionnaire is to be indicated by the use of
the equipment category code shown in section 5b above.

7. Submission of Completed Questionnaire.
    a) Two copies of the questionnaire are attached (pages A to D inclusive), one
copy for the participants' file and one for submission.

    b) The completed questionnaire is to be forwarded to F. G. Norris, Metallurgical
Engineer - Statistics, Wheeling Steel Corporation, Steubenville, Ohio, no later
than April 1, 1960.

EXHIBIT I (continued)

Metals Technical Committee - American Society for Quality Control

Survey of Equipment Used to Process Data in Studies Employing Statistical Methods

QUESTIONNAIRE - PAGE A - DATA PROCESSING EQUIPMENT AVAILABLE

Submitted By:										Date		
CHECK APPROPRIATE BOXES FOR EACH EQUIPMENT CATEGORY SHOWN BELOW	Equipment Availability					Programming						
						Availability			Sources			
Equipment Category (Refer to Section 5b for Examples)	Not available	Immediately available	Available on request within plant	Available on request within corpora-tion outside plant	Available on request outside corpora-tion on service bureau basis	No prepared programs available	A few basic programs available	Most programs required available	Write own	Manufacturer	Users Group	Personal contacts
	I	II	III	IV	V	a	b	c	d	e	f	g
A Manual Methods Only												
B Adding Machine												
C Desk Calculator												
D Desk Computer												
E Punched Card Sorter and Tabulator												
F Calculating Punch												
G Medium Scale Electronic Computer												
H Large Scale Electronic Computer												
I Other (Specify)												

EXHIBIT I (continued)

Metals Technical Committee - American Society for Quality Control
Survey of Equipment Used to Process Data in Studies Employing Statistical Methods

QUESTIONNAIRE - PAGE B - DISTRIBUTION STATISTICS

INDICATE PRINCIPAL EQUIPMENT USED IN EACH BOX USING THE FOLLOWING CATEGORY CODE

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	-
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	-
F	Calculating punch	IBM 602. IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers
X	Would not attempt within limitations of time and available equipment.	

Amount of Data N =	10			50			500			5000		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30
Average												
Median												
Mode												
Percentiles												
Range												
Standard Deviation												
Skewness												
Kurtosis												
Table of Individual Frequencies												
Table of Grouped Frequencies												
Table of Cumulative Frequencies												

EXHIBIT I (continued)

Metals Technical Committee - American Society for Quality Control
Survey of Equipment Used to Process Data in Studies Employing Statistical Methods
QUESTIONNAIRE - PAGE C - CORRELATION AND REGRESSION

INDICATE PRINCIPAL EQUIPMENT USED IN EACH BOX USING THE EQUIPMENT CATEGORY CODE

Amount of Data N =	10			50			500			5000			50			500		
Number of Independent Variables	1			1			1			1			5			5		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30
Linear Regression																		
Linear Correlation Coefficient																		
Multiple Linear Regression																		
Cross Product Extension																		
Multiple Correlation Coefficient																		
Partial Correlation Coefficient																		
Beta Coefficients																		
Non-linear Regression																		
Non-linear Correlation Coefficient																		

Amount of Data N =	5000			50			500			5000			500			5000		
Number of Independent Variables	5			10			10			10			25			25		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30
Linear Regression																		
Linear Correlation Coefficient																		
Multiple Linear Regression																		
Cross Product Extension																		
Multiple Correlation Coefficient																		
Partial Correlation Coefficient																		
Beta Coefficients																		
Non-linear Regressions																		
Non-linear Correlation Coefficient																		

EXHIBIT I (continued)

<u>Metals Technical Committee - American Society for Quality Control</u>

<u>Survey of Equipment Used to Process Data in Studies Employing Statistical Methods</u>

<u>QUESTIONNAIRE - PAGE D - ANALYSIS OF VARIANCE</u>

INDICATE PRINCIPAL EQUIPMENT USED IN EACH BOX USING THE FOLLOWING CATEGORY CODE

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	-
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	-
F	Calculating punch	IBM 602, IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers
X	Would not attempt within limitations of time and available equipment.	

No. of Replicates	2			5			10			25		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30
Single Criterion												
Double Criteria												
3 to 5 Criteria												
Over 5 Criteria												
Co-variance												
Unweighted Means Kxmxn												
Unweighted Means 2x2x2												
Weighted Means												

EXHIBIT II

SUMMARY OF REPLIES - DATA PROCESSING EQUIPMENT AVAILABLE

	FIGURES IN BOXES INDICATE NUMBER OF REPLIES	Equipment Availability					Programming						
							Availability			Sources			
		Not available	Immediately available	Available on request within plant	Available on request within corporation outside plant	Available on request outside corporation on service bureau basis	No prepared program available	A few basic programs available	Most program required available	Write own	Manufacturer	Users Group	Personal contacts
	Equipment Category (Refer to Exhibit II page 2 for Examples)	I	II	III	IV	V	a	b	c	d	e	f	g
A	Manual Methods Only	2	61	1	0	0	5	7	18	30	6	1	5
B	Adding Machine	2	57	12	`1	0	6	7	18	31	6	1	3
C	Desk Calculator	3	71	2	0	0	3	7	26	35	13	1	5
D	Desk Computer	40	7	3	8	6	13	4	4	8	9	5	3
E	Punched Card Sorter and Tabulator	3	13	44	9	1	12	7	15	17	7	6	7
F	Calculating Punch	5	5	42	8	4	10	10	10	15	6	7	4
G	Medium Scale Electronic Computer	15	6	29	16	6	7	36	15	26	26	23	17
H	Large Scale Electronic Computer	24	0	5	19	19	8	14	16	12	19	18	10
I	Other (Specify)	---	3	2	7	0	3	4	5	6	1	2	2

EXHIBIT II (continued)

SUMMARY OF REPLIES - DISTRIBUTION STATISTICS

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	--
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	--
F	Calculating punch	IBM 602, IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers
X	Would not attempt within limitations of time and available equipment.	
None	No answer received.	

HEADING SYMBOLS

N - amount of data
n - answer required in n days

AVERAGE

N	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	22	17	17	6	3	3	0	0	0	0	0	0
B	6	8	6	8	8	7	8	8	7	3	3	2
C	44	42	42	56	50	53	28	32	31	10	13	12
D	0	1	1	1	1	1	1	1	1	3	5	5
E	0	0	0	0	1	1	6	6	5	5	8	12
F	0	0	0	1	1	1	3	8	8	6	9	9
G	0	0	0	0	0	0	5	8	7	4	12	14
H	0	0	0	0	0	0	3	4	5	4	6	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	0	0	0	0	0	0	14	3	3	30	11	7
NONE	4	8	10	4	12	10	8	6	9	11	9	8

EXHIBIT II (continued)

MEDIAN

N	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	45	39	39	38	34	34	15	15	16	4	5	4
B	2	3	2	1	2	1	2	2	2	1	1	1
C	21	20	20	25	22	24	13	19	19	6	9	9
D	0	1	1	1	1	1	0	0	0	1	1	1
E	1	1	1	3	3	3	12	17	16	9	21	24
F	0	0	0	1	1	1	2	2	2	3	3	3
G	0	0	0	0	0	0	2	5	4	3	6	8
H	0	0	0	0	0	0	2	2	2	3	5	5
I	0	0	0	0	0	0	0	0	0	0	0	0
X	1	0	0	0	0	0	16	4	3	32	14	11
NONE	6	12	13	7	13	12	12	10	12	14	11	10

MODE

N	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	43	38	38	33	31	31	18	16	17	4	5	5
B	1	2	1	0	1	0	0	0	0	0	0	0
C	21	20	20	27	24	26	13	19	19	7	10	11
D	0	1	1	1	1	1	0	0	0	1	1	1
E	1	1	1	3	3	3	12	17	16	9	20	22
F	0	0	0	1	0	0	1	0	0	2	1	1
G	0	0	0	0	0	0	2	5	4	3	7	8
H	0	0	0	0	0	0	2	2	2	3	5	5
I	0	0	0	0	0	0	0	0	0	0	0	0
X	0	0	0	0	1	1	14	5	4	31	15	10
NONE	10	14	15	11	15	14	14	12	14	16	12	13

EXHIBIT II (continued)

PERCENTILES

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	26	22	22	14	12	12	5	5	5	2	3	2
B	1	2	1	0	1	0	0	0	0	0	0	0
C	32	33	32	44	41	43	19	26	26	7	11	11
D	1	2	2	2	2	2	2	2	2	3	3	5
E	0	0	0	1	1	1	8	12	11	4	11	13
F	0	0	0	1	1	1	4	5	5	4	5	6
G	0	0	0	0	0	0	3	6	6	4	8	10
H	0	0	0	0	0	0	2	2	2	3	5	4
I	0	0	0	0	0	0	0	0	0	0	0	0
X	2	1	1	1	1	1	18	6	5	33	16	11
NONE	14	16	18	13	17	16	15	12	14	16	14	14

RANGE

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	48	43	42	38	34	34	26	25	24	12	13	12
B	1	2	1	0	1	0	0	0	0	0	0	0
C	18	17	17	21	18	20	10	14	15	4	6	6
D	0	1	1	1	1	1	0	0	0	0	0	0
E	1	1	1	6	6	6	11	14	13	9	19	20
F	0	0	0	1	0	0	2	1	1	3	2	2
G	0	0	0	0	0	0	2	5	4	3	8	9
H	0	0	0	0	0	0	2	2	2	3	5	5
I	0	0	0	0	0	0	0	0	0	0	0	0
X	0	0	0	0	1	1	11	5	4	29	12	10
NONE	8	12	14	9	15	14	12	10	13	13	11	12

EXHIBIT II (continued)

STANDARD DEVIATION

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	15	12	11	4	3	2	0	1	1	0	1	1
B	2	1	0	2	2	1	1	1	0	0	0	0
C	52	52	50	56	51	53	20	30	27	8	11	10
D	0	1	2	3	3	3	3	3	5	3	3	5
E	0	0	0	1	1	1	4	4	3	2	3	6
F	0	0	0	2	2	2	6	6	6	4	8	8
G	0	0	0	0	1	1	7	12	13	6	17	21
H	0	0	0	0	0	0	4	5	6	4	7	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	0	0	0	1	1	1	20	7	4	36	16	10
NONE	7	10	13	7	12	12	11	7	11	13	10	8

SKEWNESS

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	7	6	5	3	3	2	1	1	1	0	0	0
B	1	1	0	0	1	0	0	0	0	0	0	0
C	44	44	45	46	43	44	16	24	25	7	9	8
D	2	2	2	3	3	3	3	3	4	3	3	6
E	0	0	0	0	0	0	3	5	4	2	3	4
F	0	0	0	2	2	2	4	5	4	4	6	6
G	0	0	0	0	1	1	6	9	10	3	15	18
H	0	0	0	0	0	0	2	2	3	3	5	4
I	0	0	0	0	0	0	0	0	1	0	0	1
X	10	8	8	9	8	9	26	13	10	38	21	15
NONE	12	15	16	13	15	15	15	14	14	16	14	14

EXHIBIT II (continued)

KURTOSIS

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	7	5	5	2	1	1	0	0	0	0	0	0
B	1	1	0	0	1	0	0	0	0	0	0	0
C	44	44	45	46	43	44	16	24	26	7	9	8
D	2	2	2	3	3	3	3	3	4	3	3	6
E	0	0	0	0	0	0	3	4	3	2	3	4
F	0	0	0	2	2	2	4	5	4	4	6	6
G	0	0	0	0	1	1	6	9	10	3	15	18
H	0	0	0	1	1	1	2	3	4	3	5	4
I	0	0	0	0	0	0	0	0	1	0	0	1
X	10	8	8	9	8	9	28	14	10	38	21	15
NONE	12	16	16	13	16	15	14	14	14	16	14	14

TABLE OF INDIVIDUAL FREQUENCIES

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	45	44	42	41	39	38	15	16	15	7	9	8
B	1	2	1	4	4	3	0	3	2	0	1	0
C	16	14	15	16	14	15	7	12	13	3	5	6
D	2	2	2	3	3	3	2	2	2	2	2	4
E	0	0	0	2	2	2	18	21	20	12	22	25
F	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	1	1	2	7	6	3	8	10
H	0	0	0	0	0	0	3	3	3	4	5	5
I	0	0	0	0	0	0	0	0	0	0	0	0
X	2	2	2	1	0	0	16	3	2	30	12	7
NONE	10	12	14	9	13	14	13	9	13	15	12	11

EXHIBIT II (continued)

TABLE OF GROUPED FREQUENCIES

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	41	41	39	41	40	39	14	15	14	5	7	6
B	1	2	1	2	3	2	0	1	1	0	0	0
C	15	14	15	18	15	16	9	15	14	5	7	7
D	2	2	2	3	3	3	2	2	2	2	2	4
E	0	0	0	1	0	0	18	22	21	11	23	26
F	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	1	1	2	6	6	3	7	10
H	0	0	0	0	0	0	3	3	3	4	5	5
I	0	0	0	0	0	0	0	0	0	0	0	0
X	5	5	5	2	2	2	18	5	5	34	15	9
NONE	12	12	14	9	12	13	10	7	10	12	10	9

TABLE OF CUMULATIVE FREQUENCIES

N=	10			50			500			5000		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	37	35	36	29	27	28	10	11	11	3	5	4
B	2	3	2	2	4	3	1	1	1	1	1	1
C	19	18	19	29	26	27	12	18	18	6	7	7
D	2	2	2	2	2	2	2	2	2	2	2	4
E	0	0	0	2	1	1	16	18	17	10	20	22
F	0	0	0	0	0	0	1	2	2	1	1	2
G	0	0	0	0	1	1	2	8	7	3	10	13
H	0	0	0	0	0	0	3	3	3	4	5	5
I	0	0	0	0	0	0	0	0	0	0	0	0
X	4	4	4	2	2	2	19	5	5	34	15	9
NONE	12	14	13	10	13	12	10	8	10	12	10	9

EXHIBIT II (continued)

SUMMARY OF REPLIES - CORRELATION AND REGRESSION

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	--
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	--
F	Calculating punch	IBM 602, IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers
X	Would not attempt within limitations of time and available equipment.	
None	No answer received.	

HEADING SYMBOLS

N - amount of data
V - number of independent variables
n - answer required in n days

LINEAR REGRESSION

N =	10			50			500			5000		
V =	1			1			1			1		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	10	7	7	3	2	2	0	0	0	0	0	0
B	2	2	1	2	3	1	0	0	0	0	0	0
C	54	49	51	48	49	48	14	19	17	5	7	8
D	1	2	2	3	3	3	3	5	5	1	1	3
E	0	0	0	0	0	0	0	0	1	0	0	1
F	0	0	0	1	2	2	2	5	4	5	6	6
G	0	1	1	2	3	4	4	18	23	4	22	31
H	1	1	1	2	3	3	5	7	7	5	7	8
I	0	0	0	0	1	0	0	1	0	0	1	1
X	0	0	0	5	0	0	37	7	8	42	12	9
NONE	8	14	13	10	10	13	11	14	11	14	20	9

EXHIBIT II (continued)

LINEAR REGRESSION (continued)

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	1	1	0	0	0	0	0	0	1	1	2
B	0	1	0	0	0	0	0	0	0	0	0	0
C	9	17	17	4	5	7	2	2	3	4	6	6
D	4	5	4	3	3	5	1	1	3	4	5	7
E	0	1	0	0	1	0	1	1	0	0	0	0
F	2	2	2	2	5	2	2	4	4	2	2	2
G	8	22	24	7	24	30	6	21	33	10	25	27
H	5	6	6	5	7	9	4	8	9	5	6	6
I	0	1	1	0	0	0	0	0	1	0	0	0
X	33	9	6	41	16	8	43	24	8	34	16	10
NONE	14	11	15	14	15	15	17	15	15	16	15	16

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	5	2	2	4	2	2	2	2	2	2
D	3	3	5	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	1	2	0	3	3	2	1	1	0	1	1	0
G	7	28	34	4	18	27	5	14	24	4	12	23
H	4	7	8	4	9	11	5	9	14	6	10	13
I	0	0	0	0	0	0	0	0	0	0	0	0
X	45	19	9	45	28	15	45	32	19	45	34	21
NONE	15	16	15	17	15	16	16	16	15	17	16	16

EXHIBIT II (continued)

LINEAR CORRELATION COEFFICIENT

N =	10			50			500			5000		
V =	1			1			1			1		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	4	3	3	0	0	0	0	0	0	0	0	0
B	1	1	1	1	2	1	0	0	2	0	0	0
C	58	52	53	49	50	48	13	16	16	5	5	6
D	1	2	2	3	3	3	3	5	5	1	1	3
E	0	0	0	0	0	0	0	0	0	0	0	1
F	0	0	0	1	2	2	2	5	4	5	7	6
G	0	1	1	3	4	5	4	18	24	4	23	31
H	1	1	1	1	3	3	5	7	7	5	7	8
I	0	0	0	0	0	0	0	0	0	0	0	0
X	1	1	1	5	0	0	36	10	8	41	19	10
NONE	10	15	14	13	12	14	13	15	12	15	14	11

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	1
B	0	0	0	0	0	0	0	0	0	0	0	0
C	9	18	17	3	3	6	2	2	3	4	7	7
D	4	5	4	3	3	5	1	1	3	4	5	7
E	0	1	0	0	1	0	0	0	0	0	0	0
F	2	2	2	2	5	2	3	5	4	2	2	2
G	8	22	24	8	23	31	6	20	33	10	24	27
H	5	6	6	5	7	9	4	8	9	5	6	6
I	0	0	0	0	0	0	0	0	0	0	0	0
X	35	10	8	42	18	9	46	28	11	37	19	12
NONE	13	12	15	13	16	14	14	12	13	14	13	14

EXHIBIT II (continued)
LINEAR CORRELATION COEFFICIENT (continued)

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	5	1	1	3	1	1	2	1	1	2
D	3	3	5	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	1	2	0	3	3	2	1	1	0	1	1	0
G	7	27	34	4	18	26	5	14	24	4	12	24
H	4	7	8	4	9	11	5	9	14	6	10	13
I	0	0	0	0	0	0	0	0	0	0	0	0
X	47	22	11	49	32	20	49	36	22	49	39	23
NONE	13	14	13	14	12	13	13	13	12	14	12	13

MULTIPLE LINEAR REGRESSION

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	1	1	0	0	0	0	0	0	1	1	2
B	0	0	0	0	0	0	0	0	0	0	0	0
C	9	14	15	1	2	5	2	3	3	3	6	6
D	4	5	5	3	4	6	1	1	4	4	6	8
E	0	1	0	1	2	0	1	1	0	1	1	0
F	2	2	1	1	4	2	2	4	3	1	1	1
G	7	21	24	7	23	30	4	19	35	0	25	29
H	5	6	7	5	7	9	4	8	10	5	6	8
I	0	0	0	0	0	0	0	0	0	0	0	0
X	34	12	7	44	17	8	47	28	9	37	17	9
NONE	14	14	16	14	17	16	15	12	12	14	13	13

EXHIBIT II (continued)
MULTIPLE LINEAR REGRESSION (continued)

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	4	1	1	2	1	1	1	1	1	1
D	3	4	6	1	1	1	2	2	2	1	1	1
E	1	1	0	1	1	0	1	1	0	1	1	0
F	0	1	0	1	2	2	0	0	0	0	0	0
G	7	27	36	4	18	30	5	14	25	4	12	24
H	4	7	9	4	9	11	5	9	14	6	10	13
I	0	0	0	0	0	0	0	0	0	0	0	0
X	47	21	8	48	31	16	47	35	21	46	37	22
NONE	13	14	13	16	13	14	15	14	13	17	14	15

CROSS PRODUCT EXTENSION

N =	10			50			500			5000		
V =	1			1			1			1		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	1	1	0	0	0	0	0	0	0	0	0
B	1	1	1	1	1	1	0	0	0	0	0	0
C	35	33	33	30	31	30	9	8	8	4	3	2
D	0	0	0	1	1	1	2	4	4	1	1	3
E	0	0	0	0	0	0	0	0	1	0	0	1
F	0	1	1	1	1	1	0	5	6	2	6	8
G	0	0	0	1	1	1	2	8	10	2	12	14
H	1	1	1	1	2	2	3	4	5	3	4	5
I	0	0	0	0	0	0	0	0	0	0	0	0
X	4	4	4	6	3	3	23	7	6	26	13	6
NONE	34	35	35	35	36	37	37	40	36	38	37	37

EXHIBIT II (continued)
CROSS PRODUCT EXTENSION (continued)

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	1
B	0	0	0	0	0	0	0	0	0	0	0	0
C	7	12	11	3	4	3	2	3	3	3	4	5
D	3	3	3	3	4	6	1	1	4	3	5	7
E	0	1	0	0	2	0	0	0	0	0	0	0
F	3	4	4	3	6	6	3	6	4	2	3	2
G	6	17	18	5	16	21	4	13	24	7	19	21
H	5	6	7	5	6	8	4	7	9	4	6	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	32	12	11	39	19	12	44	29	14	38	20	14
NONE	20	21	22	18	19	20	18	17	18	19	19	19

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	3	1	1	2	1	1	1	1	1	1
D	3	4	6	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	1	3	1	3	3	3	1	2	1	1	2	1
G	5	20	27	4	13	21	4	7	20	4	8	19
H	4	6	7	4	8	10	5	9	12	6	10	13
I	0	0	0	0	0	0	0	0	0	0	0	0
X	43	23	13	44	31	20	44	35	21	44	36	22
NONE	19	19	19	19	19	19	19	20	19	19	18	19

EXHIBIT II (continued)

MULTIPLE CORRELATION COEFFICIENT

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	1
B	0	0	0	0	0	0	0	0	0	0	0	0
C	10	16	16	3	3	6	1	2	3	4	7	7
D	4	4	4	3	4	6	1	1	4	4	6	8
E	0	1	0	0	1	0	0	0	0	0	0	0
F	2	2	1	2	5	2	4	6	4	2	3	2
G	7	21	25	7	24	31	5	19	35	10	25	29
H	5	6	7	5	7	9	4	8	10	5	6	8
I	0	0	0	0	0	0	0	0	0	0	0	0
X	35	13	8	43	18	9	49	30	10	39	18	10
NONE	13	13	15	13	14	13	12	10	10	12	11	11

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	5	1	1	3	1	2	3	1	2	3
D	3	4	6	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	2	3	1	3	4	3	2	2	1	2	2	1
G	7	26	36	4	17	28	5	14	25	4	11	24
H	4	7	9	4	9	11	5	9	13	6	10	13
I	0	0	0	0	0	0	0	0	0	0	0	0
X	48	22	9	49	32	18	49	35	21	49	38	22
NONE	11	13	10	14	12	12	12	12	11	13	12	12

EXHIBIT II (continued)
PARTIAL CORRELATION COEFFICIENT

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	1
B	0	0	0	0	0	0	0	0	0	0	0	0
C	8	13	15	2	4	4	1	2	3	3	5	6
D	4	4	4	3	4	6	1	1	4	4	6	8
E	0	1	0	0	1	0	0	0	0	0	0	0
F	2	2	1	2	5	2	3	5	3	2	2	1
G	7	20	22	6	20	28	5	18	30	9	22	24
H	4	5	6	4	5	7	3	6	8	4	5	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	36	15	11	44	21	12	49	31	15	40	21	15
NONE	15	16	17	15	16	17	14	13	13	14	15	14

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	4	1	1	3	1	2	3	1	2	3
D	3	4	6	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	1	2	0	3	3	2	1	1	0	1	1	0
G	6	24	31	4	17	26	4	13	24	4	12	23
H	3	5	7	3	7	9	4	8	11	5	9	12
I	0	0	0	0	0	0	0	0	0	0	0	0
X	48	25	14	49	33	20	49	35	21	49	37	22
NONE	14	15	14	15	14	15	15	15	15	15	14	15

EXHIBIT II (continued)

BETA COEFFICIENTS

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	9	14	14	2	3	4	1	3	3	3	5	5
D	4	4	4	3	4	6	1	2	5	4	6	8
E	0	1	0	0	1	0	0	0	0	0	0	0
F	2	2	1	2	5	2	3	5	3	2	2	1
G	7	19	22	7	21	28	4	16	26	9	21	23
H	4	5	6	4	5	7	3	6	8	4	5	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	35	16	12	43	21	13	48	31	16	39	22	17
NONE	15	15	17	15	16	16	16	13	15	15	15	15

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	4	1	1	2	1	2	2	1	2	2
D	3	4	6	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	1	2	0	3	3	2	1	1	0	1	1	0
G	6	23	30	3	16	25	4	12	23	3	9	22
H	3	5	7	3	7	9	4	8	12	5	9	12
I	0	0	0	0	0	0	0	0	0	0	0	0
X	47	25	15	48	33	21	48	35	22	48	38	23
NONE	15	16	14	17	15	16	16	16	15	17	16	16

EXHIBIT II (continued)
NON-LINEAR REGRESSION

N =	10			50			500			5000		
V =	1			1			1			1		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	7	6	6	4	3	3	0	0	0	0	0	0
B	1	1	1	1	1	1	0	0	0	0	0	0
C	35	36	36	29	32	33	8	11	11	4	5	5
D	1	1	1	3	3	3	3	5	6	2	2	5
E	0	0	0	0	0	0	0	1	1	0	0	0
F	0	0	0	0	0	0	0	2	2	0	2	2
G	2	3	3	3	7	7	4	16	19	4	18	22
H	1	1	1	2	3	3	4	7	6	4	7	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	11	6	6	15	7	5	33	7	8	39	18	13
NONE	19	22	22	19	20	21	24	27	23	23	24	22

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	1	1	0	0	0	0	0	0	1	1	1
B	0	0	0	0	0	0	0	0	0	0	0	0
C	5	10	8	2	2	4	1	1	2	2	3	4
D	4	5	7	3	4	6	1	1	4	4	5	7
E	0	1	0	0	1	0	0	0	0	0	0	0
F	2	2	1	2	5	2	1	3	1	2	2	1
G	8	18	21	7	18	25	4	14	25	8	19	23
H	4	6	7	4	7	9	5	10	13	4	6	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	35	16	12	41	20	12	46	31	14	38	22	15
NONE	17	17	19	17	19	18	18	16	17	17	18	18

EXHIBIT II (continued)
NON-LINEAR REGRESSION (continued)

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	2	1	1	1	1	1	1	1	1	1
D	1	2	4	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	1	2	0	1	1	0	1	2	1	1	2	1
G	6	18	27	4	12	22	5	12	20	4	10	19
H	5	9	12	5	11	15	4	9	14	5	10	13
I	0	0	0	0	0	0	0	0	0	0	0	0
X	45	25	13	47	33	20	47	33	22	47	36	24
NONE	17	19	18	17	17	17	16	17	16	17	16	17

NON-LINEAR CORRELATION COEFFICIENT

N =	10			50			500			5000		
V =	1			1			1			1		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	2	2	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	39	39	39	32	34	35	8	11	11	4	5	5
D	1	1	1	3	3	3	3	5	6	2	2	5
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	3	3	0	2	2
G	1	3	3	3	7	7	5	15	18	4	17	21
H	1	1	1	2	3	3	4	7	6	4	7	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	14	7	7	16	8	6	33	12	8	39	20	13
NONE	19	23	23	20	21	22	23	23	24	23	23	23

EXHIBIT II (continued)

NON-LINEAR CORRELATION COEFFICIENT (continued)

N =	50			500			5000			50		
V =	5			5			5			10		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	6	11	9	2	2	4	1	1	2	3	4	5
D	4	5	7	3	4	6	1	1	4	4	5	7
E	0	1	0	0	1	0	0	0	0	0	0	0
F	2	2	1	2	4	1	1	3	1	2	2	1
G	8	18	21	7	19	25	5	14	25	8	19	23
H	4	6	7	4	7	9	5	10	13	4	6	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	35	16	12	41	21	13	46	30	14	38	22	15
NONE	17	17	19	17	18	17	17	17	17	17	18	18

N =	500			5000			500			5000		
V =	10			10			25			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	2	1	1	1	1	1	1	1	1	1
D	1	2	4	1	1	1	2	2	2	1	1	1
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	2	0	1	1	0	0	2	1	1	2	1
G	6	19	27	4	13	22	5	12	20	4	10	19
H	5	9	12	5	11	15	4	9	13	5	10	13
I	0	0	0	0	0	0	0	0	0	0	0	0
X	45	25	13	47	33	20	47	33	22	47	35	24
NONE	18	18	18	17	16	17	17	17	17	17	17	17

EXHIBIT II (continued)

SUMMARY OF REPLIES - ANALYSIS OF VARIANCE

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	--
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	--
F	Calculating punch	IBM 602, IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers
X	Would not attempt within limitations of time and available equipment.	
None	No reply received.	

HEADING SYMBOLS

R - number of replicates
n - answer required in n days

SINGLE CRITERION

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	9	8	8	3	2	2	2	1	1	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	44	46	45	39	42	38	28	30	32	23	22	24
D	0	0	0	2	2	4	4	4	5	3	2	4
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	1	1	0	2	2	0	1	2	0	2	2
G	0	0	0	0	1	3	0	5	6	2	7	11
H	1	1	1	2	3	3	2	3	4	3	5	4
I	0	0	0	0	0	0	0	0	0	0	0	0
X	8	6	6	14	7	6	23	12	8	27	17	12
NONE	14	13	15	16	16	18	17	19	18	17	20	19

EXHIBIT II (continued)

DOUBLE CRITERIA

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	7	6	6	3	2	2	2	1	1	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	46	47	47	38	40	38	26	28	31	19	1	23
D	0	0	0	2	2	4	4	4	5	3	2	4
E	0	0	0	0	0	0	0	1	1	0	0	0
F	0	1	1	0	3	2	0	2	2	0	2	2
G	0	0	0	0	1	3	0	5	6	4	9	12
H	1	1	1	2	3	3	2	3	4	3	5	4
I	0	0	0	0	0	0	0	0	0	0	0	0
X	8	6	6	15	7	6	25	12	8	29	17	12
NONE	14	14	15	16	17	18	17	19	18	17	19	19

3 TO 5 CRITERIA

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	0	0	1	0	0	1	0	0	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	41	44	47	28	34	36	12	22	26	9	14	17
D	1	1	1	4	6	6	4	5	6	3	3	5
E	1	1	1	0	1	1	0	1	0	0	0	0
F	0	2	2	0	3	2	0	2	1	0	2	2
G	0	0	0	1	0	2	3	6	9	5	10	14
H	2	2	2	4	5	4	5	6	6	5	7	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	16	9	7	22	10	7	33	14	9	36	20	12
NONE	14	16	16	16	16	18	18	19	19	17	19	19

EXHIBIT II (continued)

OVER 5 CRITERIA

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	0	0	1	0	0	1	0	0	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	28	34	36	20	23	25	9	17	19	6	9	12
D	1	2	2	4	7	7	4	5	6	3	3	5
E	1	1	1	0	1	1	0	0	0	0	0	0
F	0	3	3	0	4	3	0	3	3	0	1	2
G	2	2	2	2	5	7	5	8	12	7	12	18
H	3	3	3	4	5	4	5	6	7	5	7	7
I	0	0	0	0	0	0	0	0	0	0	0	0
X	23	12	10	27	13	10	35	17	9	37	23	13
NONE	17	18	19	18	17	19	17	19	20	17	20	19

CO-VARIANCE

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	0	0	1	0	0	1	0	0	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	37	35	37	26	25	26	11	16	18	8	11	11
D	1	1	1	4	6	6	4	4	5	3	2	4
E	0	0	0	0	1	1	0	1	0	0	0	0
F	0	3	3	0	4	3	0	3	3	0	1	2
G	1	3	3	1	4	6	4	8	11	6	13	17
H	1	1	1	2	3	2	3	4	4	3	6	6
I	0	0	0	0	0	0	0	0	0	0	0	0
X	14	10	9	21	11	9	32	16	12	34	19	13
NONE	21	22	22	21	21	23	21	23	23	21	23	23

EXHIBIT II (continued)

UNWEIGHTED MEANS Kxxxn

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	0	0	1	0	0	1	0	0	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	32	32	34	21	21	22	12	11	15	10	10	12
D	1	1	1	4	6	6	4	4	5	3	2	4
E	0	0	0	0	0	0	0	1	1	0	0	0
F	0	3	3	0	4	3	0	3	3	0	2	1
G	0	2	2	1	4	6	2	6	7	3	7	11
H	1	1	1	2	3	2	2	4	5	2	5	6
I	0	0	0	0	0	0	0	0	0	0	0	0
X	15	9	7	20	10	7	26	16	10	29	18	12
NONE	26	27	28	27	27	30	29	30	30	28	31	30

UNWEIGHTED MEANS 2x2x2

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	0	0	1	0	0	1	0	0	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	32	33	34	20	20	22	12	11	15	10	10	13
D	1	1	1	4	6	6	4	4	5	3	2	4
E	0	0	0	0	0	0	0	1	1	0	0	1
F	0	3	3	0	4	3	0	3	3	0	2	1
G	0	2	2	1	4	6	2	6	7	3	8	10
H	1	1	1	3	4	3	4	5	5	4	6	6
I	0	0	0	0	0	0	0	0	0	0	0	0
X	15	9	7	20	10	7	24	15	10	27	17	11
NONE	26	26	28	27	27	29	29	30	30	28	30	30

EXHIBIT II (continued)

WEIGHTED MEANS

R=	2			5			10			25		
n =	1	7	30	1	7	30	1	7	30	1	7	30
CAT. A	1	0	0	1	0	0	1	0	0	1	0	0
B	0	1	0	0	1	0	0	1	0	0	1	0
C	32	32	34	20	20	23	12	11	16	10	10	13
D	1	1	1	4	6	6	4	4	5	3	2	4
E	0	0	0	0	0	0	0	1	1	0	0	0
F	0	3	3	0	4	3	0	3	3	0	2	1
G	0	2	2	1	4	6	2	6	7	3	8	11
H	1	1	1	2	3	2	3	5	5	3	6	6
I	0	0	0	0	0	0	0	0	0	0	0	0
X	15	10	7	21	10	7	27	16	10	29	18	12
NONE	26	26	28	27	28	29	27	29	29	27	29	29

EXHIBIT III

MOST FREQUENTLY RECEIVED REPLY

Equipment Availability

Manual methods only	Immediately available	61
Adding machine	Immediately available	57
Desk calculator	Immediately available	71
Desk computer	Not available	40
Punched card sorter and tabulator	Available on request within plant	44
Calculating punch	Available on request within plant	42
Medium scale electronic computer	Available on request within plant	29
Large scale electronic computer	Not available	24
Other	Available on request within corporation outside plant	7

Programming Availability

Manual methods only	Most programs required available	18
Adding machines	Most programs required available	18
Desk calculator	Most programs required available	26
Desk computer	No prepared programs available	13
Punched card sorter and tabulator	Most programs required available	15
Calculating punch	Tie for all classifications	10 each
Medium scale electronic computer	A few basic programs available	36
Large scale electronic computer	Most programs required available	16
Other	Most programs required available	5

EXHIBIT III (continued)

<u>Programming Sources</u>

Manual methods only	Write own	30
Adding machine	Write own	31
Desk calculator	Write own	35
Desk computer	Manufacturer	9
Punch card sorter and tabulator	Write own	17
Calculating punch	Write own	15
Medium scale electronic computer	Write own Manufacturer	26 26
Large scale electronic computer	Manufacturer	19
Other	Write own	6

EXHIBIT III (continued)

MOST FREQUENTLY RECEIVED REPLY

Distribution Statistics

LETTERS IN BOX INDICATE EQUIPMENT CATEGORY, FIGURES INDICATE NUMBER OF REPLIES

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	-
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	-
F	Calculating punch	IBM 602, IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers
X	Would not attempt within limitations of time and available equipment.	

Amount of Data N =	10			50			500			5000		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30
Average	C 44	C 42	C 42	C 56	C 50	C 53	C 28	C 32	C 31	X 30	C 13	G 14
Median	A 45	A 39	A 39	A 34	A 34	A 15	A 15	C 19	C 19	X 32	E 21	E 24
Mode	A 43	A 38	A 38	A 33	A 31	A 31	A 18	E 17	E 17	X 31	E 20	E 22
Percentiles	C 32	C 33	C 32	C 44	C 41	C 43	C 19	C 26	C 26	X 33	X 16	- 14
Range	A 48	A 43	A 42	A 38	A 34	A 34	A 26	A 25	A 24	X 29	A 13	E 20
Standard Deviation	C 52	C 52	C 50	C 56	C 51	C 53	C-X 20	C 30	C 27	X 36	G 17	G 21
Skewness	C 44	C 44	C 45	C 46	C 43	C 44	X 26	C 24	C 25	X 38	X 21	G 18
Kurtosis	C 44	C 44	C 45	C 46	C 43	C 44	X 28	C 24	C 26	X 38	X 21	G 18
Table of Individual Frequencies	A 45	A 44	A 42	A 41	A 39	A 38	E 18	E 21	E 20	X 30	E 22	E 25
Table of Grouped Frequencies	A 41	A 41	A 39	A 41	A 40	A 39	E-X 18	E 22	E 21	X 34	E 23	E 26
Table of Cumulative Frequencies	A 37	A 35	A 36	A-C 29	A 27	A 28	X 19	C-E 18	C 18	X 34	E 20	E 22

EXHIBIT III (continued)

MOST FREQUENTLY RECEIVED REPLY

Correlation and Regression

LETTERS IN BOX INDICATE EQUIPMENT CATEGORY, FIGURES INDICATE NUMBER OF REPLIES

Amount of Data N =	10			50			500			5000			50			500		
Number of Independent Variables	1			1			1			1			5			5		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30
Linear Regression	C 54	C 49	C 51	C 48	C 49	C 48	X 37	C 19	G 23	X 42	G 22	G 31	X 33	G 22	G 24	X 41	G 24	G 30
Linear Correlation Coefficient	C 58	C 52	C 53	C 49	C 50	C 48	X 36	C 18	G 24	X 41	G 23	G 31	X 35	G 22	G 24	X 42	G 23	G 31
Multiple Linear Regression													X 34	G 21	G 24	X 44	G 23	G 30
Cross Product Extension	C 35	- 35	- 35	- 35	C 36	C 37	X 37	- 40	- 36	- 38	- 37	- 37	X 32	- 21	- 22	X 39	X- 19	G 21
Multiple Correlation Coefficient													X 35	G 21	G 25	X 43	G 24	G 31
Partial Correlation Coefficient													X 36	G 20	G 22	X 44	X 21	G 28
Beta Coefficients													X 35	G 19	G 22	X 43	GX 21	G 28
Non-linear Regression	C 35	C 36	C 36	C 29	C 32	C 33	X 33	- 27	- 23	X 39	X 24	GX 22	X 35	G 18	G 21	X 41	G 20	G 25
Non-linear Correlation Coefficient	C 39	C 39	C 39	C 32	C 34	C 35	X 33	- 23	- 24	X 39	- 23	- 23	X 35	G 18	G 21	X 41	I 21	G 25

Amount of Data N =	5000			50			500			5000			500			5000		
Number of Independent Variables	5			10			10			10			25			25		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30	1	7	30
Linear Regression	X 43	X 24	G 33	X 34	G 25	G 27	X 45	X 28	G 34	X 45	X 28	G 27	X 45	X 32	G 24	X 45	X 34	G 23
Linear Correlation Coefficient	X 46	X 28	G 33	X 37	G 24	G 27	X 47	X 27	G 34	X 49	X 32	G 26	X 49	X 36	G 24	X 49	X 39	G 24
Multiple Linear Regression	X 47	X 28	G 35	X 37	G 25	G 29	X 47	X 27	G 36	X 48	X 31	G 30	X 47	X 35	G 25	X 46	X 37	G 24
Cross Product Extension	X 44	X 29	G 24	X 38	X 20	G 21	X 43	X 23	G 27	X 44	X 31	G 21	X 44	X 35	G 21	X 44	X 36	X 22
Multiple Correlation Coefficient	X 49	X 30	G 35	X 39	G 25	G 29	X 48	X 26	G 36	X 49	X 32	G 28	X 49	X 35	G 25	X 49	X 38	G 24
Partial Correlation Coefficient	X 49	X 31	G 30	X 40	X 22	G 24	X 48	X 25	G 31	X 49	X 33	G 26	X 49	X 35	G 24	X 49	X 37	G 23
Beta Coefficients	X 48	X 31	G 26	X 39	X 22	G 23	X 47	X 25	G 30	X 48	X 33	G 25	X 48	X 35	G 23	X 48	X 38	G 23
Non-linear Regressions	X 46	X 31	G 25	X 38	X 22	G 23	X 45	X 25	G 27	X 47	X 33	G 22	X 47	X 33	G 22	X 47	X 36	X 24
Non-linear Correlation Coefficient	X 46	X 30	G 25	X 38	X 22	G 23	X 45	X 25	G 27	X 47	X 33	G 22	X 47	X 33	G 20	X 47	X 35	X 24

EXHIBIT III (continued)

MOST FREQUENTLY RECEIVED REPLY

Analysis of Variance

LETTERS IN BOX INDICATE EQUIPMENT CATEGORY, FIGURES INDICATE NUMBER OF REPLIES

Category	Equipment	Example
A	Manual methods only	Paper and pencil
B	Adding machine	-
C	Desk calculator	Friden, Marchant, Monroe
D	Desk computer	IBM 610, IBM 1620
E	Punched card sorter and tabulator	-
F	Calculating punch	IBM 602, IBM 604, IBM 607
G	Medium scale electronic computer	IBM 650
H	Large scale electronic computer	IBM 700 series or larger
I	Other (specify)	Includes X-Y plotters and analog computers
X	Would not attempt within limitations of time and available equipment.	

No. of Replicates	2			5			10			25		
Answer Required in n days n =	1	7	30	1	7	30	1	7	30	1	7	30
Single Criterion	C 44	C 46	C 45	C 39	C 42	C 38	C 28	C 30	C 32	X 27	C 22	C 24
Double Criteria	C 46	C 47	C 47	C 38	C 40	C 38	C 26	C 28	C 31	X 29	C 19	C 23
3 to 5 Criteria	C 41	C 44	C 47	C 28	C 34	C 36	X 33	C 22	C 26	X 36	X 20	- 19
Over 5 Criteria	C 28	C 34	C 36	X 27	C 23	C 25	X 35	- 19	- 20	X 37	X 23	- 19
Co-variance	C 37	C 35	C 37	C 26	C 25	C 26	X 21	- 23	- 23	X 21	- 23	- 23
Unweighted Means Kxxxn	C 32	C 32	C 34	- 27	- 27	- 30	- 29	- 30	- 30	- 28	- 31	- 30
Unweighted Means 2x2x2	C 32	C 33	- 34	- 27	- 27	- 29	- 29	- 30	- 30	- 28	- 30	- 30
Weighted Means	C 32	- 32	- 34	- 27	- 28	- 29	- 27	- 29	- 29	X 29	- 29	- 29
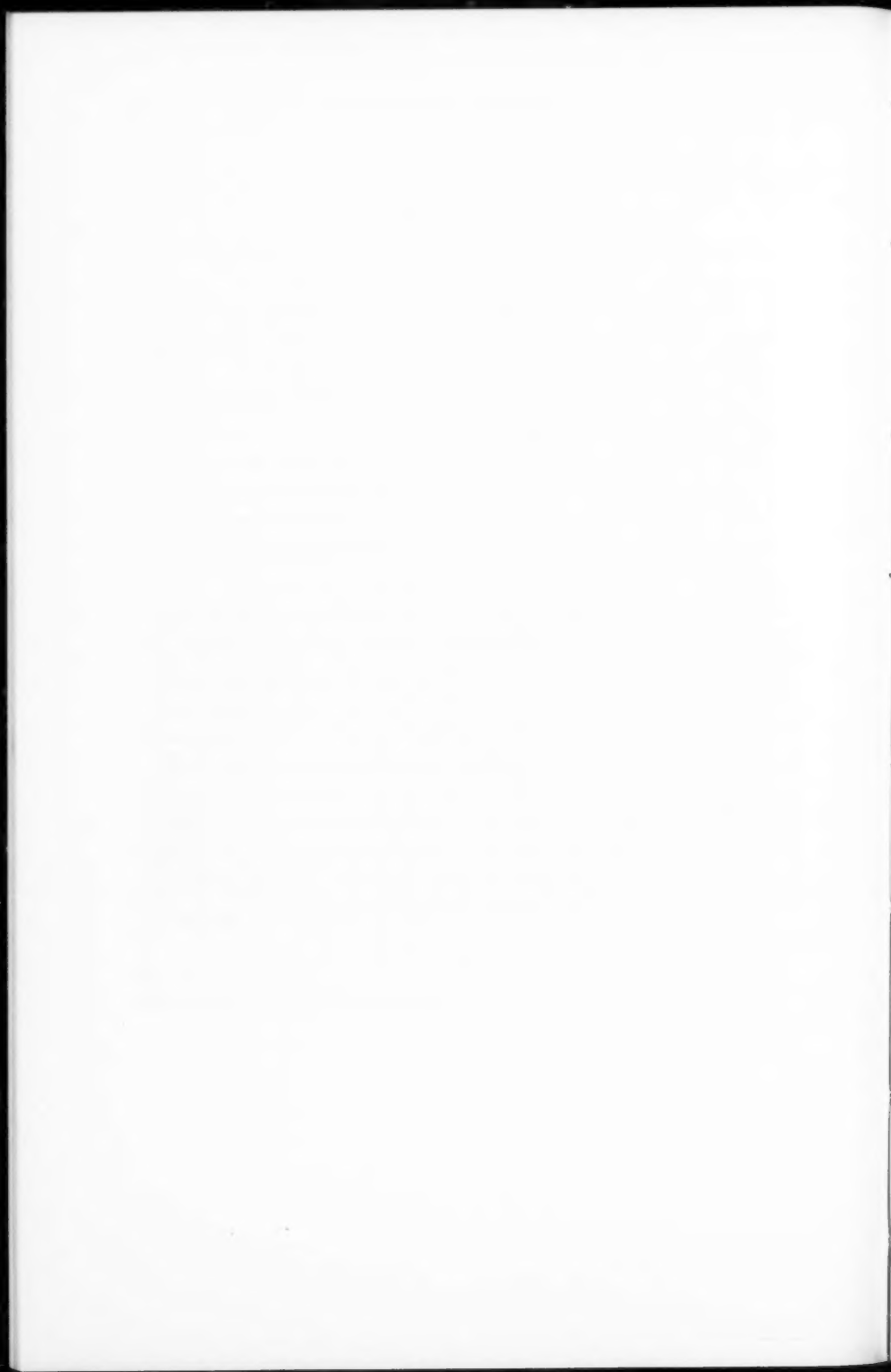
MECHANIZED RETRIEVAL OF SCIENTIFIC INFORMATION

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INTRODUCTION

"File It to Find It," was the title of the lead article in the September 1959 issue of INDUSTRIAL QUALITY CONTROL. In it, Ervin F. Taylor, Chairman of the Bibliography Committee, described the American Society for Quality Control literature classification scheme. "Classification," he said, "is not for the purpose of merely filing. ... Classification is for the purpose of finding." In an Editorial Note, Mason Wescott added that this system was developed as "a solution to a major problem - aiding the ASQC member in locating the literature he wants from the vast quantities supplied by the ASQC."

The classification scheme, which resembles the Dewey Decimal System of library cataloging, is a closed-end one, of three major categories: methodology or techniques are limited to a maximum of 1000 classifications; functional classifications are limited to 100; and industry and business classifications cannot exceed 1000.

For a relatively homogeneous collection of literature, in which no very great depth of indexing is required to locate an article or articles on a particular subject, such a classification scheme works satisfactorily. For a collection of many thousands of documents of heterogeneous subject-matter, an open-ended system - that is, one with no limit on the number or type of index terms - is more suitable. This method makes it unnecessary to force a document into pre-existing categories.

During the last 15 years, many individuals and organizations have been concerned with the development of Information Storage and Retrieval systems. Both the Senate and the House of Representatives of the United States Congress have conducted investigations and have made appropriations for such work. Some Government agencies which have been doing or contracting work, or making investigations of systems, are the Library of Congress, the Central Intelligence Agency, the Patent Office, the National Bureau of Standards, and the National Science Foundation, to name just a few. Many private organizations and industries have also been evolving or investigating systems.

Efforts have been of two general types: those interested in building machines, and those concerned with developing theory. Conventionally trained librarians have for the most part, been hostile to both groups, usually claiming that "library science" methods were already doing a sufficient job, and/or that the goals of the "information scientists" were impossible to achieve.

True, library method are effective - up to a point. But both librarians and documentalists are at the mercy of their filing systems. No amount of mechanization will retrieve anything which has been mis-filed or mis-coded, or not indexed in sufficient depth to make it retrievable on demand.

The first published article to give serious consideration to the mechanization of literature searching was one in the July 1945 issue of the ATLANTIC, by Vannevar Bush, then head of the Office of Scientific Research and Development. The first machine for information storage and retrieval, called the Rapid Selector, was developed by Dr. Ralph R. Shaw, now at Rutgers University, then librarian of the Department of Agriculture. Since that time, several other special purpose machines have been produced, and a number of organizations have come to use general purpose computers to store and retrieve information. The largest of the users of a general purpose computer is the Armed Services Technical Information Agency, which uses a UNIVAC Solid State 90 computer on its mechanized file of over 250,000 research and development reports on all government contracts since the end of World War II. Current growth rate of this collection is 30,000 documents per year.

ASQC LCS Code 000:00:000

Contrary to much popular opinion, there is nothing magic about electronic comput-
ers, so that they cannot retrieve information that was not properly abstracted and
indexed in the first place. Consequently, the more recent emphasis has shifted some-
what from machine design to theory of indexing and retrieval.

WHY DOES AN ORGANIZATION NEED AN INFORMATION STORAGE AND RETRIEVAL SYSTEM?
Whenever a new project is undertaken, many problems must be resolved: Establish-
ment of personnel requirements, budgets and schedules; specifications and standards,
quality control procedures, testing programs; component and vendor selection, sub-
contract letting and a host of other technical questions - all requiring extensive
research of one sort or another. Most new projects have a number of elements in com-
mon with others currently in progress or already completed, either within one's own
organization or elsewhere in the world. Hence FORTUNE Magazine, in an article called
"How to Cope with Information", in the September 1960 issue, says, "Scientists and
engineers are haunted by the fear - indeed the certainty - that they are working on
problems that have already been solved and whose solutions have been published some-
where."

Investigation of a particularly knotty problem often delays work for weeks. All
too often, after such delay, the truth of this quotation is evident. It has even
happened that a man in the same office, whom no one thought to consult, says, "Pardon
me, gentlemen. I couldn't help overhearing. We faced this same problem a couple of
years ago, on Project X. I was involved in it, and wrote up the final report." All
too frequently he may add, "If we can just find it."

FORTUNE quotes an estimated minimum of 10 percent of the nation's public and
private $12.5 billion research and development budget going for pointless duplication
of effort. Unfortunately, such duplication is often faster and even cheaper than
finding the appropriate documents. Technical information is being generated at such
a stupendous rate that it is extremely difficult to keep up with what one needs to
know.

The WALL STREET JOURNAL of December 20, 1960, says, under the title "Fishing for
Facts," "Every 24 hours enough technical papers are turned out around the globe to
fill seven sets of the 24-volume Encyclopedia Britannica." FORTUNE (quoted above) says,
"Mankind is learning things so fast that it's a problem how to store information so it
can be found when needed. Not finding it costs the U.S. over $1 billion a year."

HOW IS AN INFORMATION STORAGE SYSTEM DEVELOPED?
The three most prominent indexing philosophies which have been developed are the
Uniterm system of Mortimer Taube, the descriptor concept of Calvin Mooers, and the
"role indicator" method of Western Reserve University. Taube advocates using for
indexing purposes the key words which actually appear in the document itself. Mooers'
system uses as "descriptors" the basic concepts with which the document is concerned.
Western Reserve goes a step further than either of these, conveying the relationship
between terms and ideas by means of "role indicators." Another philosophy, particular-
ly valuable for certain types of subject matter, embodies hierarchical classifications.
(Example: airedale, terrier, dog, animal, mammal, vertebrate.) For most collections,
some combination of uniterms, descriptors and role indicators is probably the most
nearly ideal. For instance, a combination of the two words "cooling" and "water"
requires a "role indicator" to disclose whether a document deals with the use of water
as a cooling agent, or the process of the cooling of water.

Once a suitable indexing plan has been devised, there are many different ways in
which the reference information from technical documents may be stored for effective
retrieval. Some of these are cross-referenced files in folders; hand-entries in note-
books or on cards; edge-notched cards which can be sorted manually with a "needle";
"peekaboo" cards; punched cards with or without microfilm inserts, manipulated by
either tabulating equipment or computer; or magnetic tape for computer processing. The
choice of method will be largely influenced by the size and complexity of the document
collection, and the depth of indexing required for efficient retrieval.

It must be re-emphasized that the first consideration is not the mechanics of how
the references are to be stored and the information retrieved, but the gathering of
pertinent documents into a central location, in such a form that they may be processed
by some means for most efficacious use. The processing requires, for each document,
the appropriate bibliographical facts; a relevant, informational type abstract; and the
selection of the key terms, or descriptors, by which the subject matter should be
indexed.

In any organization, the logical first step in implementing an Information Storage and Retrieval Program is the issuance of a Management Procedure, establishing the existence of an Information Center and outlining the method by which documents will be submitted and processed for inclusion in the system. Certainly some discriminatory efforts will have to be expended, so that only documents of future reference value will be included. Likewise, measures must be instigated for obtaining documents which are pertinent.

A cover sheet for each article is desirable, listing its security classification, contract number applicable, corporate author, project author, individual author(s), date of the report, and the file location, as well as the title or subject of the document. Next on the form is an abstract, as short as possible, but of sufficient length to contain the significant information described in the referenced document. Finally, the key terms or "descriptors" of the document are indicated. These may be underlined in the text of the abstract, supplemented, at the bottom of the form, by a list of any terms implied by the content of the document or required for effectual indexing. Also in this list, any abbreviations used should be written out in full.

Authors of internally generated documents may be asked to fill out the cover sheet for each document they submit. For externally generated documents, such will necessarily be accomplished by personnel of the Information Center. To be done properly, this requires personnel who have cognizance of the subject matter. Clerical help cannot be given this assignment.

In the Center, the document is assigned an accession number, and the descriptors are "edited." Some judgment must be exercised as to whether they are too many or too few, too general or too specific, or consistent with the indexing system. Next, a Thesaurus is consulted, when appropriate, to determine which of several synonymous descriptors is the one being used in the "standard" index, and which ones should be cross-referenced. This is primarily to insure that a requestor will get all available information pertaining to the subject of his question, regardless of whether he uses the exact words in the index, or similar ones. Unfortunately, there is no such thing as a standard thesaurus of all technical subjects, so that each Center is obliged to develop its own in accordance with the subject matter with which it is dealing. There are, however, many sources of assistance in such development, and their use is recommended.

Cover sheet, descriptor selection, and accession number assignment having been completed, the information from the document is ready to be stored for future retrieval.

There are two basically different methods of storing information. In one, under suitable identification of a specific document, all descriptive terms pertaining to that document are listed. In other words, storage is document by document. This method is the simpler for input purposes. But the output is much more complex and time consuming, under most circumstances. Supposing, for example, someone requests all the documents pertaining to wire-wrap connectors. To fulfill this request it is necessary to look at the terms listed under every document in the collection, to see which ones are actually identified as containing information on wire-wrap connectors.

The other method, referred to as an inverted matrix, uses the descriptors as headers, and lists under each descriptive term all the documents in which this term is discussed. That is, storage is descriptor by descriptor. Input by this method is more time consuming and slightly more complex, but output (customer service) is generally much simpler and faster.

Depending upon the storage system selected, terms may be recorded in code or in straight English words. A dictionary for translation purposes is required if terms are coded. With a computer, this is quite simple to use. As a document collection builds, the rate of growth of the descriptor list far exceeds that of the number of documents. When the collection reaches somewhere between 1,000 and 3,000 documents, descriptors will probably not be added so rapidly - there will be much greater usage of already-established ones - but it is inconceivable that the time will ever be reached when no new descriptive terms are required.

If one is using a document-by-document storage system, to enter a new document one simply records the document accession number in order, with all pertinent terms under it. These will include bibliographical information, as well as technical terms. If one uses the inverted matrix method, the document accession number will be listed under each of the appropriate descriptive terms, including the bibliographical ones. A simple example of this type system is the "peekaboo" card, in which hole position

indicates document accession number. One would assemble all the appropriate descriptor cards into one stack, and punch the number into all cards simultaneously. Numbers are represented by the x and y coordinates of the hold. Thus, document number 5623 is represented by a hold punched 56 spaces to the right on the x axis, and 23 spaces up on the y axis. When the document collection exceed the number of holes the card will accommodate, it is necessary to make a duplicate set of cards of another color, to take care of the additional document numbers. In this method, it is difficult to remove the accession number of a document which has become obsolete. Using a computer, the removal of an obsolete document number is quite simple.

An easy way to expedite dissemination of information from the collection is to have all document cover sheets reproduced in compressed form in an "Abstract Book," by document accession number, with copies of this book liberally dispersed in every area of the organization that might have need for the technical information. How this book is used will be described later.

NOW THE INFORMATION IS STORED. HOW IS IT RETRIEVED WHEN NEEDED?
There are three methods by which information may be requested:
1.	The question to be answered may be written out and mailed to the Center.
2.	When a question is received by telephone, it is written out by the person taking the message, and read back to the requestor for verification, just as is a telegram telephoned to Western Union. This is to insure that there is no misunderstanding as to how the question was stated, and what was meant.
3.	One who needs information may come to the Center in person, deliver his question, and perhaps wait for an answer - depending upon the method by which the retrieval system operates. Again, the question is written out for verification.

As in the case of input to the system, the Thesaurus is consulted, when appropriate, to insure that the requestor will get all available information pertaining to the subject of his question, regardless of whether he has used the exact words in the index, or similar ones.

The document collection is then searched for the accession numbers of the documents which have in common this combination of descriptive terms, or an acceptable modification of it. A computer retrieval system may then actually print out the abstracts of the applicable documents, as is done at ASTIA.

If abstracts are not printed out as a part of the searching system, a list of accession numbers of applicable documents is obtained. Next, the cover sheets (or appropriate entries in the Abstract Book) are scanned to verify that all the documents actually do appear to apply to the question. If there are any which do not, these are crossed off the list.

Answering, like requesting, may be done in three ways:
1.	To answer a request received by mail, the list of applicable document accession numbers, or the complete abstracts as produced by computer, is mailed to the requestor.
2.	If the question was received by telephone, the accession numbers are given to the requestor by phone. (He may also receive the written list, if he wishes.) Then he consults the Abstract Book at his desk.
3.	If the question was delivered in person, and the system is such that he may obtain a reply while he waits, the requestor may consult the appropriate abstracts in the Center, either in the Abstract Book or from the computer-produced text.

In this last case, he requests copies of the documents he wants to see. The Abstract Book (and the cover sheet for each document) tells him to file locations.

Having supplied the requestor with the list of accession numbers for the abstracts in answer to his question, the Information Storage and Retrieval Center then enters the following data, supplemented by follow-up information from the requestor, in the "Use" file:

1.	The question. The same type of question may be asked frequently. If so, the Center can then give a requestor the names of others who have similar interests, with whom he may want to get in touch.
2.	The name of the requestor. This, of course, ties in with the previous statement. It will also enable the Center to accumulate a "who is interested in what" register, so that at some future time it may inform such people, ahead of direct requests, when some new material comes in which should be of inter-

est to them.

3. The descriptors. A good set of descriptors simply does not descend like manna from heaven. Only experience will determine what are good and what are not good. If there is a descriptor which has been in the index for a couple of years without ever having been used in a request, the chances are that it was a poor choice and should be eliminated. The converse is not necessarily true. If a descriptor has had a very high rate of usage, it may be too general, and should be broken down into two or three more specific ones.

4. The document numbers applicable to the question (this information obtained from the requestor). This serves two purposes: 1) A record of the accession numbers of the documents which actually provided good answers to a particular question will enable the Center to give improved service in the future; and 2) It gives a clue to obsolescence. If a document has been in the system for several years without ever having been used for reference, the chances are that it should be archived.

With an efficient Information Storage and Retrieval System, such as has been described, one should be able to find the documents he needs when he needs them, subject only to the Center's acquiring the documents in the first place. Thus it should be possible to eliminate much costly duplication of effort, effecting substantial savings in both time and money. Joe Blow may still have to say, when faced with a problem on a new project, "Gee, I know I have read a solution to this problem somewhere." But instead of saying, "The Good Lord only knows where that document, is," he should be able to say, "EUREKA!"

SUMMARY

"A Must: Better Information Retrieval" is the title of an article appearing in the January 11, 1960, issue of CHEMICAL ENGINEERING. The article begins, "If engineers are to become more efficient, one need is to be able to find what's gone before. Mechanized searching's now a must. In the world of engineering, the price of ignorance is technological surprise. With the acceleration of engineering development in the '60's, chemical engineers will become more and more concerned with this threat. Engineers must exercise particular care to avoid these traps:

Not knowing what one ought to know.
Not being able to recall what one once knew.
Starting a project already completed elsewhere.
Repeating work already in the public domain.
Knowing less about a given subject than the organized intelligence network of your competitor."

The problem is further complicated because a large and significant part of the world's scientific literature is published in foreign languages, with which so few of our American scientists are familiar. Currently, more technical articles are being published in Russian than in German; more in Japanese than in French; and more in Chinese than in Italian. Computer translation of these foreign publications is one facet of Information Storage and Retrieval currently under development. Russia has a huge task force of highly trained scientists working in its information retrieval center (known as VINITI), a large part of which is devoted to translating and disseminating to every part of the Soviet Union the scientific knowledge contained in technical publications from all over the world.

Various undertakings, both government and private, are well along in this country, for the solution of the information problem.

The first step in the establishment of an Information Storage and Retrieval System is to develop the philosophy and indexing system which will most efficiently and economically serve the needs of the particular organization. If the document collection anticipated is relatively small and homogeneous, a simple index and retrieval system will suffice. If the collection is to be extensive and somewhat heterogeneous, with considerable depth and complexity of indexing required for effective retrieval, then it is advisable to use a computer for storage and retrieval of information. But the system should be well thought out and developed first, before putting it on a computer. Otherwise, expensive experimentation may cause one to declare the computer, rather than the system, ineffectual. The developmental stage may very well require one to two and a half years, depending upon the size and the capability of the staff assigned to the task.

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20. Taube, Mortimer, Coordinate Indexing, Vol. I, II and III, Documentation Incorporated, Washington, 1953, 1954, 1955

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NOTE: AD numbers are ASTIA indentification of documents available through that agency, to holders of government research and development contracts.

DO YOU MAKE THESE Q.C. MISTAKES IN BUYER
AND SELLER RELATIONS?

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"Our inspection department just rejected the entire shipment of space pumps we worked so hard to get in from Satellite Accessories, Inc., this week!"

The Purchasing Manager's reaction to this announcement went from an expression of utter disbelief, through despair, and on to mounting anger. If you were to ask Mr. Beyer, "Who made the Q.C. mistake involved in the assembly floor crisis this rejection will precipitate?" his first words might touch upon thoughts like, "If you look hard enough you can find a reason for rejecting anything that was ever built - and our inspectors don't seem to realize we are supposed to be in business to make a profit."

Of course, if instead you were talking to Mr. Cue, the Q.C. Manager, he might answer the question by explaining, "We have a vendor-rating plan, which has been in effect for some time now, and I wonder how much attention Purchasing has paid to the rating for Satellite Accessories, Inc. Why, they act as if they are surprised at this rejection! That supplier's rating is borderline."

What would a trip to the vendor's plant produce as an answer to the question? We were surprised; they didn't berate receiving inspection of the Count Down Repeater Co. They described a complicated engineering change procedure this customer had: a few hundred changes per week, the disposition of material in process was not always clearly stated, "We don't know about this case yet, but probably Engineering, Inspection, Production Control and Purchasing there do not really agree yet whether these particular pumps should be reworked, scrapped, or accepted as is. They were made to the same drawings as the last shipment, which was accepted. Maybe we'll get a change notice tomorrow that will tell us to do something different with them, and we'll have to reply that they've already been shipped."

"Actually", the Satellite spokesman, Mr. George Maker, went on, "they need the pumps quite desperately. They will probably find a way to use them. Last month we had separate visits from representatives of their Purchasing, Quality Control, and Engineering Departments. Their interests were different, and it would be impossible for us simultaneously to do what each group wanted. So we give first priority to what Purchasing wants. Frankly, we wouldn't be sorry if they took their business elsewhere. We do have customers with whom it is much easier to work."

We thanked him for his revealing explanation.

Who made the Q.C. mistake? Everyone we heard from can't be right.

Actually no one was correct. That's what makes carrying product through its cycle from concept to delivery to ultimate customer, at times, so frustrating. You probably don't have to go far back in your memory to list a number of other Q.C. situations that were mixed up in some way with buyer and seller relations.

"We found the rest of that lot you rejected from that sample to be less defective than the AQL we agreed upon with you," one vendor patiently explains.

"It wasn't like that when it left our plant."

ASQC LCS Code 351:00:000

"You must have a new inspector on that job. "

"Your other plant accepted a shipment from this same lot! "

"But you didn't say that in your specifications. We figured our costs on the stated requirements. "

"Other customers are finding our product satisfactory. "

You can imagine the customer's inspection representative's replies.

And while this list grows, we hear Purchasing earnestly explaining, "No one else will agree to make it for us. "

Or asking,

"Do you realize what kind of a delivery date we would get if we had those requirements ?"

The questions, accusations, and words of advice multiply as we get further into specific problems of quality of design, and of quality of conformance of parts to the design requirements.

Are companies really making Q. C. mistakes? If situations like these are not uncommon in week-to-week activities - yes.

When quality is really controlled, problems such as these approach the vanishing point. This means, of course, Q. C. has to go beyond control charts and sampling plans - far beyond records that tell or imply to someone else that they are not doing as well as they should.

It is, of course, impossible to become specific without restricting ourselves to a given plant - whether it be a seller or a buyer - in a given industry. We have felt this paper could perhaps be more useful in describing fundamentals. If they appeal to you, it will be your task to adapt them to fit your problems.

The first six fundamentals we call defect-prevention ones; and the last five, defect-correction fundamentals.

1) The buyer and seller should exchange outlines of standard practice. Bring out into the open, early in the relationship, the differences that may exist. Reaching the necessary agreements at that time will be considerably less costly in time, tempers, and treasury department matters.

2) Tolerances should be considered as absolute. By this statement we mean that all deviations should be submitted to the equivalent of Material Review Board action; we mean consideration of the acceptance of non-serious deviations provided they are non-repetitive, or provided suitable corrective action had been initiated. We also recommend against the practice of reaching agreements between buyer and seller as to Acceptable Quality Levels for specific groups of characteristics. Such practice is in effect saying, "The engineer who set the limits has been somewhat conservative, in view of his limited knowledge as to just how far he can go without getting into some difficulty. " In most cases that statement is quite true. But the practice in effect goes further, "--so, we shall have the Quality Control Department (or some buyer-seller group) set a percent defective of a distribution that can extend beyond the tolerance limits, and the sampling plan will be selected that has a high probability of acceptance of this percent defective. " That, unfortunately, is setting new, broader limits yet with the same limited knowledge as to just how far one can go without getting into some difficulty.

Under the eleventh fundamental, "Realistic Tolerances Can Be Determined, " we shall describe how one can find how far he can go.

3) Get production started on the right foot. If five units, parts, or what have you, are selected at random from among the first fifteen to twenty produced, they can be extremely useful in helping to comply with this fundamental.

A tag on each unit should record three readings of each important characteristic as measured on the seller's equipment, and some lack of repeatability must be evident! If not, the equipment is not sensitive enough to show its own variability. Sometimes that situation obscures important product variability.

The range among the five units, when converted to standard deviation by the d_2 factor, should show at least eight standard deviations for the tolerance as a rough but not-to-be-neglected check on process capability. (1) The extra two standard deviations beyond the conventional six allow for some of the sampling error and for unavoidable shifts of process average coming from new raw material, replaced tools, and change of operator.

Three more sets of entries should go on the tags from the readings on the buyer's equipment, when such is used for acceptance purposes. Important improvements in equipment repeatability and correlation may be indicated by the comparison of the two sets of entries.

Then find out if all five units will fit, function, or whatever will be expected of them. It is not unusual to find that some important characteristic had not been specified in the original design.

4) Classify characteristics functionally, not defects operationally, for acceptance sampling assurance levels. Far more agreement as to the classification of the same characteristics by several classifiers can be obtained. A characteristic is called MATING if its primary function is to contribute to a fit or an over-all circuit characteristic. It is INDEPENDENT if the assembly can fail to function when it alone is beyond limits. And it is UTILITY when it is neither mating nor independent, being primarily descriptive rather than functional.

This fundamental recognizes the variation of opinion among people who are classifying defects as CRITICAL, MAJOR, or MINOR, on the basis of the seriousness of the possible consequence of the characteristic being defective.

Independent characteristics get a tight sampling assurance level; mating a more liberal level on the basis that two or more will combine to give a combination characteristic, the risk for which should equal that of the independent one; and utility gets only a sufficiently large sample size to identify that the characteristic is not defective to a widespread extent in the lot.

Conventionally critical characteristics are assigned 100 percent inspection, major a tight AQL, and minor a more liberal AQL. If one interprets this to mean, respectively, nothing, a little, and a moderate amount beyond tolerance is to be permitted, then the previous discussion under the second fundamental suggests this thought: the engineer can increase the tolerance a moderate amount on minors and a little on majors -- now they would all be "critical" from the viewpoint that nothing more should be allowed beyond limits.

The real problem seems to be that the practice of classifying defects is an attempt to control quality through inspection. Inspection does not control quality effectively; quality is best built into the product by those who produce it, the manufacturing people.

5) Control production to keep parts away from the region of the limits. Duplicate gages, instruments, and test rigs seldom give extremely close, similar results because of many factors, the worst of which is usually wear differences. Whenever parts are near limits, as when material is sorted or screened at a limit, the seller and the buyer can find themselves mixed up in some discussions not particularly conducive to good relations. Process quality control devices for complying with this fundamental are, in order of decreasing complexity, $\overline{X}$ and R control charts, narrow limit gaging plans, and the PRE-Control technique.

(1) Naturally, as more data later becomes available, the statistical precision of this check can be improved.

6) The buyer should inspect to a defect-prevention schedule. When the buyer inspects for acceptance outside the seller's plant, first priority should be given any sets of the five tagged parts described under fundamental number three. Next on priority should be the first full lot of any production run, followed on the list by those parts urgently needed by the buyer. Last, but also on the priority list should come any material that, say, had been received more than two weeks ago. It is unfortunate when a detectable error is not found soon enough so that more material is produced with the same error.

The next five fundamentals are defect-correction ones:

7) The buyer should furnish statistical evidence of the quality characteristics found by inspection. These, preferably, should be in the form of histograms of random samples. The seller can do a better and quicker job of correcting a defective condition when he sees that the trouble is a narrow distribution way off center, or two distributions in different positions, or a distribution that is too wide.

8) The buyer should return one example of each rejection found, even though the parts may be usable with or without rework by the buyer. Trouble shoot- ing by the seller can be considerably facilitated when he has more than a description or a picture of the questionable part. Being able to handle the part, trying it in the manufacturing fixtures and inspection gages can cut short many weeks of supposition as to what could have caused the apparent difficulty. In several cases, the returned part made it immediately clear that the trouble was centered in the buyer's gages or interpretation of requirements rather than the seller's. But it took the return of the part to the seller to bring the fact out quickly and clearly.

9) Personal contacts between the buyer's representatives through its Purchasing Department and the seller's Sales Department on quality questions are to be preferred, whenever possible, over telephone or mail contacts. We have wit- nessed weeks of misunderstanding cleared up by one short visit too many times not to include this point as one of the fundamentals for good relations.

10) The seller should investigate troubles in his plant in such a way as not to bring about an inadvertant change in quality standards. This principle also has an application among the buyer's inspectors. Inspectors have a natural tendency to tighten up, subconsciously, in their evaluation of product for about a week or two if recent operating troubles are mentioned to them, as may well be the case during a search for clues as to how something undesirable got by. Unnecessary rejections can be avoided often if this fundamental is kept in mind.

11) Realistic tolerances can be determined, if the need is sufficiently urgent, to ease a buyer-seller problem. The technique is called experimentation by the Random Balance method. It involves checking out the separate effects of many variables simultaneously with about 30 test runs. Each variable is arranged at random in its levels with every other one. The analysis consists of a correlation plot of each tested characteristic against the output. Because of the random assignment of levels, the regression line in each case represents the estimate of the effect of each variable alone, all the others having been balanced out and going into the cause of scatter of the points about the regression line. The plot involving the most important variable will have the greatest shape and least scatter. A simple graphical procedure on each plot shows the extent of inputs that will guarantee outputs within their limits.

We should like to go on. We have strong feelings about survey teams, source inspection, and vendor-rating plans - all contributing to Q.C. mistakes in buyer and seller relations. Understandably, the subject is a big one - never completely finished no matter how well you approach it in your business. But it might pay to start to go after those fundamentals which have a major influence on these relations.

A CONTRACTOR WRITES A MILITARY SPECIFICATION

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BACKGROUND

In the late 1950's the Special Projects Office of the Bureau of Ordnance, United States Navy was established. Its urgent mission was to develop an operational Fleet Ballistic Missile Weapon System by 1960. This Fleet Ballistic Missile was to have the capability of being launched as a long-range missile with a thermonuclear warhead from submerged nuclear-powered submarines. It was to be the United States' dramatic answer to the Soviet challenge in the complicated techni-political space age.

The tightly-compressed time schedule for accomplishing this fantastic goal incorporated a program for Quality Assurance and Reliability to insure that the vehicle and a vast complex of support equipment would be operational at the time it was needed. The Missile Evaluation Branch of Navy BuOrd's Naval Ordnance Laboratory, Corona, California was given the responsibility for developing with the contractors a quality and reliability system that would assure needed dependability during fleet operation.

OBJECTIVES

The planners of NOL, Corona, determined that several basic ground rules must apply.

(1) Since there was such diversity of responsibility, it was necessary to establish minimum contractor quality and reliability system standards.

(2) As a means of determining progress made by contractors in fulfilling the quality and reliability responsibilities, a system for determining progress against these standards was required.

(3) Since various government inspection agencies would have cognizance over the operation of these different contractors and since training of government inspection and quality personnel varied from agency to agency, it was necessary to establish a guide for these agencies to utilize in implementing the quality and reliability program. It was also necessary to have a means for reviewing the progress made by these agencies in implementing and exercising surveillance over the contractors' programs.

The magnitude of the job presented by these basic ground rules and the need to develop such specifications within a very short time period required the immediate application of experienced quality and reliability personnel to this program. Further, since these requirements were to be incorporated in the contracts of the FBMWS program, it was necessary to have these documents prepared with the contractors' viewpoint taken into consideration.

SELECTION OF CONTRACTOR

To accomplish the project objectives and to meet the timetable involved, it was necessary for NOL, Corona, to select for this task an experienced company which could make the proper type of talent available for the length of time needed. Chance Vought was selected as the contractor to prepare the specifications, which was titled: "Development and Documentation of Quality Control and Reliability Standards for the Fleet Ballistic Missile Program".

At Chance Vought, the Quality Control Department assigned the responsibility for successful completion of this program to the Chief of Quality and Reliability Development. It was his responsibility to recruit the key Quality Control and Engineering personnel required for the project and to direct the Chance Vought effort.

DEFINITION OF TASK

Management of this effort boiled down essentially to three key elements:

(1) Clearly defined objectives and policies.

(2) Rapid and regular communication and co-ordination with NOL, Corona.

(3) Assignment of a fulltime, experienced quality-reliability team to prepare the specification.

TEAM OPERATING POLICIES

Team operating policies were established as follows:

(1) A special task group from Quality Control and Engineering will be assigned fulltime to the development and preparation of the subject standards and rating systems under the direction of the Chief of Quality and Reliability Development.

(2) The standards and rating systems developed should be acceptable to Chance Vought, if applied, as a test of the business soundness of the standards.

(3) The continuous reliability and quality control concept in use at Chance Vought and expressed in the Department of Defense document developed by the Ad Hoc Committee for Guided Missile Reliability shall be the basis for the standards.

(4) The standards and the rating system should be developed on a functional rather than a phase basis (i.e., pre-prototype, prototype, production, etc.).

(5) All key sections of the standards shall include the "Concept and Approach" applicable to the subject.

(6) The concept of "feedback loops" shall be prominent in all phases of the document, with particular emphasis on contractor - subcontractor relationships.

(7) The standards will determine policies and end results of a contractor system rather than dictating "how to do".

(8) The rating systems will be developed to highlight weaknesses as a guide to correction rather than for "rejecting" contractors.

TEAM OPERATION

Since this was a handpicked team, experienced in the Quality Control and Reliability fields both with aircraft, (F7U-3, F8U-1 and -2) and with the Regulus I and II guided missiles, each member was assigned responsibilities, according to his experience, to develop basic outlines for the various sections of the documents. Included in this breakdown were sections on "General Management", "Design Control", "Procurement Control" "Production Control", "Data Reporting and Corrective Action". It was recognized early in the development of these standards that MIL-Q-9858, NAVORD instruction 4355.22 and MIL-G-14461 (ORD) all described general Quality Control requirements applicable to military contractors but it had been determined by BUORD that, for the Fleet Ballistic Missile Weapon System, each of these documents, although generally applicable, was not sufficiently specific. The team, however, was required to be completely familiar with the key specifications associated with the project.

DOCUMENT DISCUSSION

The key document developed was MIL-Q-21549A (NOrd) Military Specification, "Quality Assurance Program Requirements for Fleet Ballistic Missile Weapon System Contractors". This was the very heart of the Quality Assurance Program for the Fleet Ballistic Missile System. Its intent was to define the requirements for the contractors and to be included as part of the contract for each of the programs.

A review of the document will show that major emphasis was applied to design control and procurement control as well as to the traditional quality control effort associated with production. One of the most vital areas of emphasis was concerned with test equipment design and fabrication. The reason for this was that the combined experience of Chance Vought and NOL, Corona had indicated that many of the difficulties of prior programs had centered around lack of compatibility of the test equipment to the

product and poor co-ordination of test equipment used by prime contractors and subcontractors.

The result was a demanding document for a very demanding program.

The second document, entitled "Guide for Evaluation of Contractor Quality Assurance Program", was intended for the use of NOL, Corona in evaluating contractors associated with the program. It was recognized that in any contractor evaluation the contractor and the cognizant government inspection agency had to be part of the team. The purpose of the survey was for corrective action purposes.

The third document, entitled "Guide for Government Inspection Agency", was prepared as a co-ordinating document between the various government services supporting this specific program. Its purpose was to establish basic ground rules for the inspection agencies in harmony with the overall quality assurance program and to highlight those areas that were considered essential for assuring the success of the program. It recognized, however, that the management of each of these inspection agencies differed and that the contractors being serviced varied both in the scope and the type of product involved. But it did provide a guide by which the agencies working with NOL, Corona could better direct their efforts to the FBMWS program in the minimum time scale involved.

The fourth document, entitled "Guide for Review of Government Inspection Agency", was developed for joint use by NOL, Corona and the specific government inspection agencies. Its purpose was to highlight potential trouble areas and to provide a basis for improvements, recognizing the basic autonomy of the inspection agency.

GENERAL OBSERVATIONS

During the preparation of these documents, both contractor and government viewpoints were expressed and serious debates with regard to emphasis as well as to requirements were resolved. In some cases the contractors' viewpoints prevailed and in others the experience of the government as a basic surveillance agency prevailed. The vast majority of the requirements, however, were mutually agreed upon very early in the program.

Events subsequent to the publication of these documents leads one to draw some conclusions.

(1) A contractors' viewpoint did permit the publication of requirements that had been tested in industry.

(2) The FBMWS Quality Assurance program was significantly accelerated by this effort.

(3) Two groups, one government, one industry, had their viewpoints enlarged by this effort --- to the benefit of both.

(4) Any contribution that this effort makes, however modest, improves the deterrent capability of our country at a time when it is needed most. This is the real payoff.
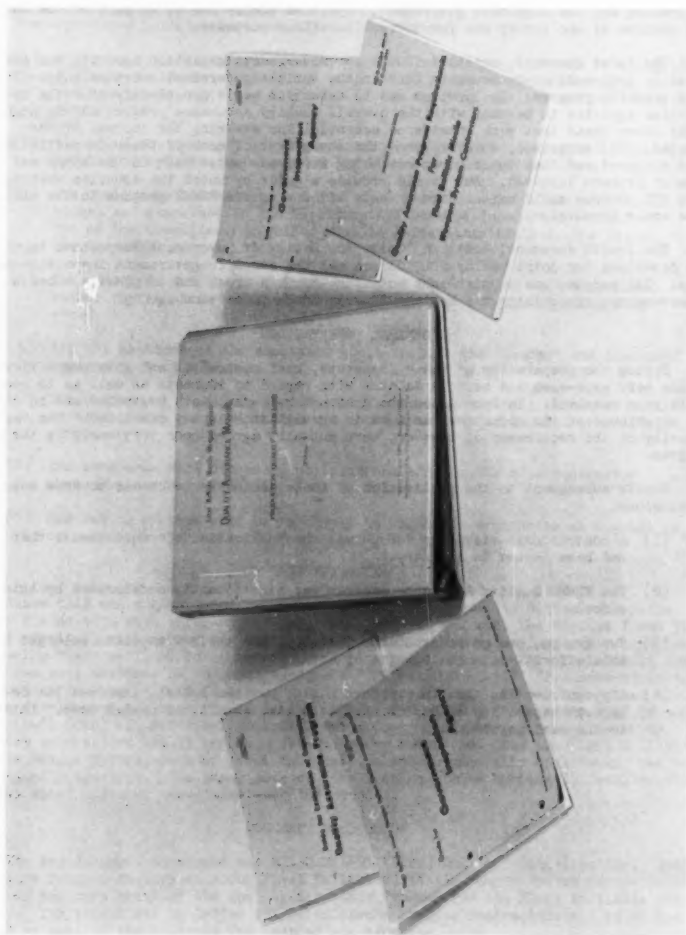
MCTSA SEEKS QUANTITY WITH CONFIDENCE

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Generally speaking, you have to give something to get something. The Military Clothing and Textile Supply Agency accepts this quid pro quo. The Agency is seeking the installation of quality control by all contractors or potential contractors; it guarantees that an acceptable quality control system will require less red tape for the acceptance and shipment of product. Before discussing the quality control program, the mission of the Agency must be placed in proper perspective.

MISSION

First, the Agency is an outgrowth of the Department of Defense Single Manager concept for specific commodity fields. It was established to eliminate existence of duplication and overlapping in procurement, storage and distribution, as well as other phases of supply management. For clothing and textiles, the Secretary of Defense designated the Secretary of the Army, then Mr. Brucker, as the Single Manager. Under him, through the Army chain of command, Major General Webster Anderson was appointed Executive Director of MCTSA in July 1956. The Agency integrated the four separate supply systems of the Army, Navy, Air Force, and Marine Corps and became a unified supply agency with full responsibility to meet the wholesale requirements of the four Services. A separate paper could be written about its success and overall achievements. For example, millions of dollars have been saved by reducing the number of storage and distribution locations, use of an electronic receiving network, use of an automatic data processing system for a sensitive inventory control, the standardization of items, the modernization of procurement methods, and others.

Second, the scope of items assigned to the Agency includes more than is denoted by the words "clothing and textiles." This specific commodity field encompasses clothing in the sense of coats, trousers, drawers, and the like; textiles such as yard goods, undershirts and hosiery; and many related items such as various types of footwear and boots, tents, body armor, mattresses, field packs, embroidered and metal insignia, belts, flags, tapes, webbing, helmets. The Agency is responsible for approximately 5,000 different generic* items. Dollar-wise, the title of an informative address by General Anderson is explicit, namely, "A Two Billion Dollar Quality Operation."
    (1)
Operation."   The vastness of its supply system is evident. What may not be so evident, however, is the tremendous, continuing, and challenging responsibility to maintain a supply readiness keyed to peacetime needs and economy and instantly convertible to emergency conditions.

Third, the Agency is comparable to any large industrial firm in having specific responsibilities for prudent management, efficient operations, and the maintenance of an economical inventory. It is equally concerned with satisfying its customers (the four Services). Being a military organization, it has the added responsibility for military preparedness. Current world conditions indicate the ever-present powder keg which could explode into a brush fire, guerrilla or limited war. Therefore, the Agency must be geared to supply large quantities of product with confidence to such areas directly and rapidly. Toward this end, its active and potential contractors must be depended upon to produce quality product.

GENEALOGY

The basic principles of quality control by the Government were developed in an excellent article entitled "Quality Control Management in the Department of Defense," written by John J. Riordan, Office of the Assistant Secretary of Defense, Supply and
    (2)
Logistics.   The Department of Defense promulgated a series of broad policies to encompass total quality control. The Army, Navy, and Air Force had to translate the

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* The term "generic" refers to a kind of item. For example: Shoe, Men's, Service, Dress, Black or Shoe, Men's, Service, Dress, Brown. Each size of the item is assigned a federal stock number; therefore, each size is a line item.

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(3)

policies into practice. An Army Regulation   stated that when there is satisfactory
evidence of good quality, which is the result of inspection and/or quality control by
the contractor, Army inspection will be adjusted to a minimum consistent with assurance
that supplies conform to contractual requirements.

OBJECTIVE

Major General Anderson set his sights and charted a course to obtain his QC
(quantity with confidence) through industry QC (quality control). He launched an
intensive program to promote product quality control, with emphasis on statistical
quality control techniques by Agency contractors, as well as by the soft-goods indus-
tries as a whole. Farsightedly, the success of this program envisaged better product,
increased industry capability, and timely delivery. What follows summarizes the
progress made, the status quo, and the projected plans, all of which, it is hoped,
will be sufficiently informative to stimulate and increase industry interest in
becoming Agency contractors.

ACHIEVEMENTS

A procurement innovation directly associated with the objective of product quality
control is worthy of first mention, namely, the Qualified Manufacturers List for
clothing items. This list was developed to eliminate marginal operators and irrespon-
sible bidders and, conversely, encourage and increase capable and responsible bidders.
The QML requires that before a firm may be placed on any bidders list, it complete a
detailed application and questionnaire which demonstrate satisfactory manufacturing
capability, technical know-how, quality of production, business and financial integ-
rity, and adequate plant facilities and trained labor. Applications are then reviewed
by a board which is assisted by a staff of legal and technical specialists. Plant
visits are made to verify information furnished by applicants. Only firms placed on
the QML may submit bids.

The quality control program for the soft-goods industries had to be evolutionary
because it was revolutionary. Hence, the Agency planned to execute the overall plan
in three successive phases, as follows: First, contractor testing of materials or
components; second, contractor examination of product; third, contractor control of
production processes. It was foreseen that the successful execution of the three would
result in the ultimate objective, viz., a quality control system in effect by each
Agency contractor. The first two phases have been fully implemented; the final phase
is underway.

Contractor Testing

Agency contracts require that contractors test, or have tested, materials or
component parts to be used in the manufacture of the end item, as well as the end item
when testing is applicable. The contracts provide that, at the time of presentation
of a lot for government acceptance, contractors also present certified laboratory test
reports on all tests required by component and end item specifications. These test
reports are examined in detail by the Quality Control Representative (formerly called
Inspector) to whom the lot is presented. If the reports show that all test require-
ments have been met, they are taken as direct evidence of component acceptability.
The interests of the Government are protected through the medium of verification
testing. Occasionally, with a frequency based on quality history, the Quality Control
Representative draws a sample of the product tested and sends it, accompanied by the
contractor-furnished test results, to the MCTSA laboratory in Philadelphia. The same
tests are performed on the material and the results are compared and evaluated, in
detail, with those furnished by the contractor. Correlation is the objective so that
acceptance can continue to be made on plant test results.

The Agency developed an attendant program to promote more process control by
component manufacturers. The program is called Acceptable Suppliers List. In brief,
it provides that if the supplier of a component part establishes and maintains an
acceptable quality control system, acceptance will be made on the receipt of an ASL
certificate in lieu of test results. The Agency protects its interest by occasional
verification testing, examination, and plant surveys. The ASL was commenced for
certain designated components. Currently, it is applicable to the majority of compo-
nents procured by MCTSA contractors. Hopeful that this paper may be used as an
immediate or future reference, the components on the list are: artificial leather,

shoulder pads, sleeve heads, coatfronts; labels, woven, printed; snap fasteners,
insignia buttons, metal hardware; webbing and tape, braid, woven lace, draw cords,
draw strings, elastic webbing, elastic tape and cord, ribbon, hanger loops; plastic
and pearl buttons, plastic buckles; plywood, for other than furniture; silesia,
buckram, cheesecloth; rope, string, twine; sewing thread, yarn, gimp; slide fasteners;
small leather components; barrier material, moisture and vapor transmission; burlap
and burlap tubing; naphthalene; fiberboard, paperboard, packaging paper and wooden
shipping containers; steel strapping; polyethylene bags; bottom fillers; counters,
outsoles, insoles, midsoles, welting, heel pads; nails and tacks, shoe last hardware,
fiber counters, shanks, eyelets; counters (plastic); heels, soles, bases; box toes,
felt tongue lining, shoe laces, insole reinforcing tape (gem duck), vamp lining, vamp
and quarter doubler. For an up-to-date listing of items associated with this program,
interested firms should direct their queries to the Technical Division, MCTSA.

Contractor Examination

Agency contracts require contractors to perform visual examinations set forth
in the contracts and/or specification quality assurance provisions before presenting
lots for government acceptance. Such provisions stipulate the standards against which
to inspect such as the classification of defects, acceptable quality levels, and the
use of statistical sampling plans. Government acceptability of the contractor's
examination is determined by means of verification examinations. The contractor is
required to score on an examination record all defects found in the sample examined
for each lot. At the beginning of a contract, the Quality Control Representative
performs his verification by examining a sample of the product from the lot offered
by the contractor as being acceptable. If his findings are within the acceptable
quality levels specified in the contract, and are statistically comparable to those
of the contractor, the lot is accepted. After a predetermined number of lots are
found to be acceptable and comparable, acceptance is then made on contractor results
without verification. Thereafter, the Quality Control Representative performs his
verification examination only on a skip-lot basis, providing the reliability of
contractor results is maintained. This procedure enables a contractor to ship his
product at times more convenient to him and to be reimbursed more quickly for product
shipment.

ULTIMATE GOAL
CONTRACTOR QUALITY CONTROL SYSTEM

It is worthwhile repeating that the two phases, contractor testing and
contractor examination, are now de facto accomplishments; that this third phase is
only the early stage of implementation. Contrary to expectation, Agency contractors
did not voluntarily install the third important measure, namely, production process
control. As a consequence, Agency Quality Control Representatives have had to
accomplish too many lot-by-lot verifications because of statistical noncomparability
and, in some cases, because of outright rejection of lots presented by contractors
as being acceptable. Nevertheless, the objective of accepting with reliability is
within reach. Since the fall of last year, the Agency developed a Quality Control
System Requirements clause and placed it into Invitations for Bids for several items
as pilot runs. In essence, the requirements provide that a contractor will design,
document, and establish his own quality control system subject to the approval of the
Agency QCR. When a satisfactory system is in effect, the Agency QCR's visit to the
plant is not only infrequent but, for the most part, confined to an appraisal of the
system including a review of the objective quality evidence. It is now within the
realm of reality that quality control systems by contractors will be as automatic as
contractor testing and examination have become.

INDUSTRY ENDORSEMENTS OF QUALITY CONTROL SYSTEM

Below are excerpts from letters sent to the Agency attesting to benefits
realized:

> "...The advantages gained thereby are most gratifying. In the
> final examination alone, there has been a noticeable decrease in
> the number of defects found. As a result of this, I have been
> able to cut down my examination force considerably. Through
> the process inspection stations in the production line, we have
> eliminated almost completely any stoppages in production because
> of defective parts. Despite the necessary adjustment with the

installation of any new system, there has been no interference
with production. On the contrary, the production foremen have
found it to be of valuable assistance to them ..."

"...We are well pleased with the workings of this plan and
I am sure it is improving our quality on garments ..."

"...It has taken us quite a while to digest the meaning of
this new plan of production control. I will readily admit
that it is quite helpful to us in making possible a better
quality of production and we are quite happy and proud of
attaining this status ..."

"...The five most frequently cited advantages were: Reduction
in cost, saves overall production time, less scrap, less repair
and reworked material, and higher quality level of product.
Other advantages are: elimination of 100% inspection, smaller
production of seconds, free workers for other jobs, less
machinery repair, more production per worker, increase in pay
to workers, quicker acceptance by Q.M. inspector, defective
raw materials spotted before put into production, increase in
sales, uncovered better production methods, gained better
knowledge of workers' capabilities, and greater customer
confidence."

PROMOTIONAL EFFORTS

The above resume of the entire program belies the immense amount of effort
expended, the trials, the tribulations, etc. The Military Clothing and Textile Supply
Agency has received praiseworthy recognition for fostering quality control in the
soft-goods industries, which were virtually in the dark concerning the application of
this science. It authored such pamphlets and manuals as "This Is Contractor Testing,"
"This Is Contractor Examination," "Blueprint for Quality Control," "Contractor
Inspection," "Evaluation of a Quality Control System." It conducted seminars, confer-
ences and meetings, and prepared newspaper and magazine articles.

TRAINING

The wherewithal to accomplish so much was a challenge in itself. From the very
beginning, a major training program in statistical quality control was launched.
Military Clothing and Textile Field Inspection Offices were redesignated as Military
Clothing and Textile Quality Control Offices. Personnel who met the necessary qualifi-
cations were converted from end-item inspectors to quality control personnel. The
average age of field personnel has been reduced from an average age of 55 years to
approximately 42 years. The institution of a career development program resulted in
increasing the staff with college-caliber personnel. To date approximately 300 Agency
procurement inspection personnel have been trained in statistical quality control at
the Quartermaster School, Fort Lee, Virginia. Key civilian personnel and military
officers have received advanced quality control training at the Air Force Institute of
Technology, Wright-Patterson Air Force Base, Ohio; at the Ordnance School, Rock Island,
Illinois; and at selected civilian universities. The Agency played an important part
in the development of an advanced quality control course now also being given at the
Quartermaster School, Fort Lee, Virginia. All of this training resulted in the
promotional effort of the Agency to bring quality control to the attention of the
industries with which it does business. Over 150 quality control plans have been
developed by Agency QCRs, tailored to individual contractor plants. Recently, this
Agency collaborated with the Philadelphia Section of the American Society for Quality
Control and developed a basic course in quality control which is being given at the
Philadelphia Quartermaster Center. The course was designed especially for manufac-
turers in the clothing field. There are no educational prerequisites for the course.
Its principal objective is to teach a basic understanding of quality control princi-
ples and practices.

OPTIMA-SEE

Admittedly, this is a play on words. Whether unique or not, it expresses the
Agency conviction that contractors will "see the best" in what a quality control
system will do for them. In retrospect, it took years before the use of a scientific

sampling plan in the inspection of product was accepted as a valid, ingenious, and economical method to obtain a representative picture of a mass or lot of product. The same could be said about the acceptance of automation, now increasing at a rapid rate. Unquestionably, quality control is here to stay; the threshold has been reached. Only the final spurt remains. To this end the Agency will continue to foster and assist industry associations, as well as individual contractors, in the establishment of a "QC" (quality control) system so that it can realize its "QC" (quantity with confidence).

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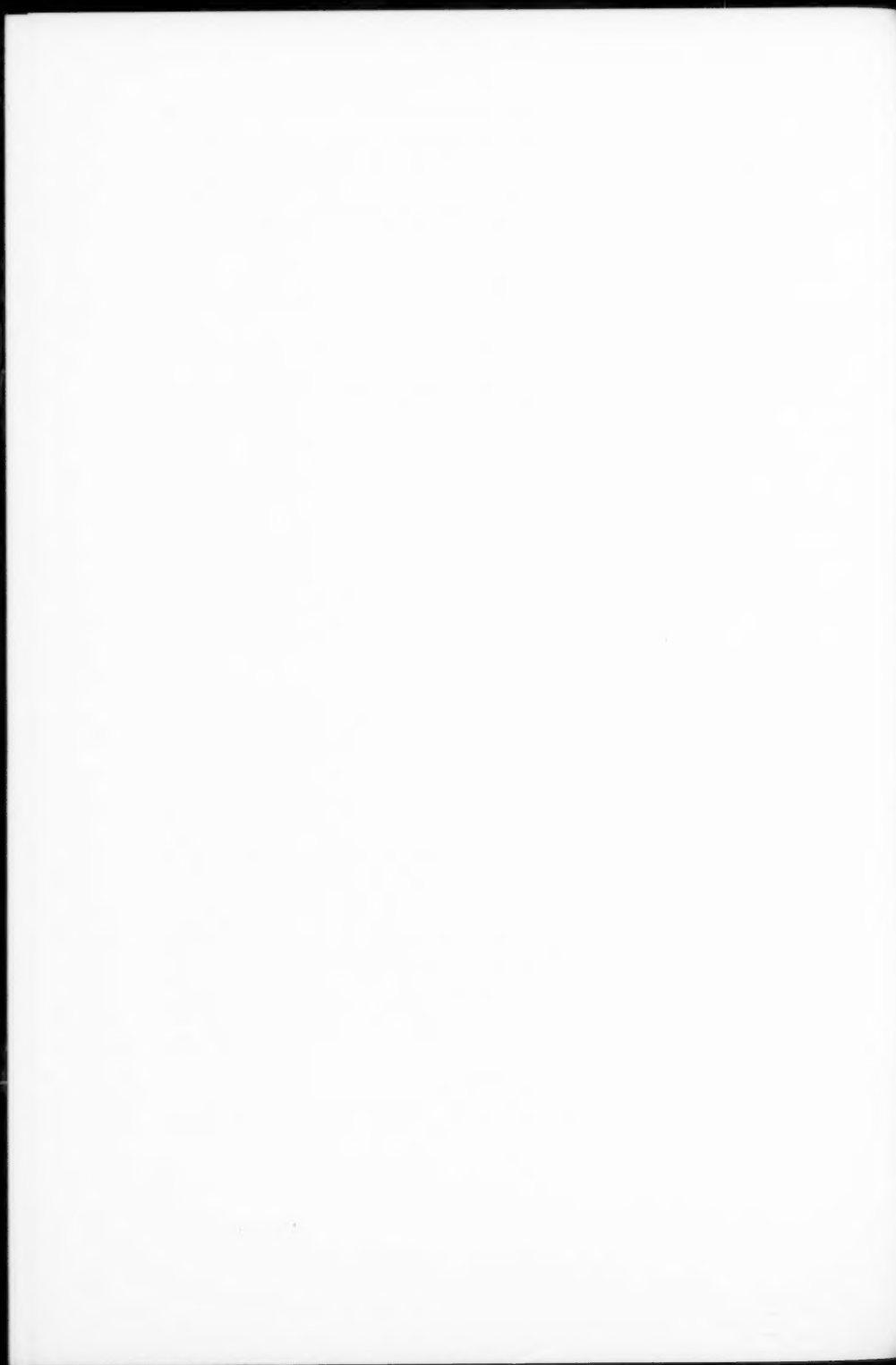
SIGNS OF OUR TIME WHICH FORECAST QUALITY

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Quality Control today has been caught up in an era of rapid, we might say, explosive, change. One American philosopher has noted that, "It took man 475,000 years to arrive at the agricultural revolution - another 25,000 to come to the industrial revolution. We have arrived at the Space Age in 150 years - and while we do not know where we go from here, we can be sure that we will go there fast." The evidences of change - whether it be time compression in the development, production, test, and operational phase of weapon systems; a transition of buying complex systems in small quantities; or increased subcontracting by the prime weapon systems' contractor - are in evidence all about us.

Let's look at some of the changes in research, development and production that have affected our way of life. It is well known history that a full scale mobilization was started during World War II. At this point in time, the Air Force as well as industry were aware that the existing methods of dealing with quality problems were inadequate. There were many signs indicating that the old inspection systems had been overtaken by the rush of technological advances in products. Industry and the Air Force had also come face to face with the fact that practical and economic considerations made it essential that duplication of inspection between the Government and contractors be eliminated. It was after this point in time, that the "Statistical Quality Control movement," gained its full momentum. Statistical quality control was developed to serve the needs of large production quantities and did a much better job than the old inspection systems.

In the latter part of the 50s, however, we were in a state of transition. Where aircraft had been produced in hundreds they were now being produced in tens. Qualitative superiority was no longer being based upon the nation's ability to produce large quantities in which acceptance of a few defective items could be tolerated. Instead, the emphasis was on small quantities of very complex systems of aircraft and missiles requiring the utmost precision and quality in order that they would perform their mission the first and only time used. This trend will be greatly accelerated during the 60s. The Sputnik awakening also made the long term step-by-step process of development, prototyping, service testing, and getting into production impractical. National survival necessitated compression of the research, development and production cycles. This "time compression," as it was popularly called, imposed a terrific burden on everyone. This was particularly true of quality control, since definitive criteria for acceptance purposes was no longer readily available. Quality control found it increasingly important to keep a close liaison with engineering and production.

Another significant sign of the times is the tremendous increase in subcontracting by the prime weapon systems contractor. Where the prime contractor previously had a relatively simple receiving operation to verify incoming material, the increased complexity of subsystems defied any meaningful reinspection upon receipt. This, of course, considerably broadened the role of quality control. Industry as well as the Air Force found it necessary to station quality control personnel at all locations where contract services were being performed. There is considerable concern over the implementation of this system. Responsibility cannot be firmly placed and there are indications that with so many personnel involved each may be placing too much dependence upon the other.

The increase in subcontract activity has resulted in a corresponding increase in requests for Government source inspection. This practice is not in accordance with AMC policy. The full impact of these requests for source inspection is difficult to ascertain. One integrating contractor, for example, has 8 major associate and 34 supporting contractors. Each of these 42 contractors have Air Force prime contracts against which they issue a considerable number of subcontracts. The exact number of subcontracts issued by these associate contractors is not known but the integrating contractor alone buys material from 3,000 subcontractors involving some 27,000 items with the dollar value estimated at approximately 65% of the total dollar value of the contract. This integrating contractor is known to issue some 300 subcontracts each day and virtually all of these requests are approved for Government source inspection. The Air Force, as a result, is finding it difficult to cope with this increase in requests for source inspection. There are indications that some contractors may be relying on Government source inspection to provide assurance that material conforms

to the requirements of the contract. This, of course, constitutes non-compliance with contractual requirements for vendor selection and vendor control. In addition to MIL-Q-9858, there are several contractual documents, such as: MIL-R-26674, USAF Specification Bulletin Nr 510, and AFBMC Exhibit 58-10, which contain specific requirements for vendor selection and vendor control systems. It should be noted that we in the Air Force do not perform source inspection for the benefit of the prime contractor, but act as an extension of the AFQCR in the prime contractor's plant on material which is too complex to verify upon receipt at the prime plant.

Second and third tier subcontracting has also become a way of life in present day methods of contracting and requires considerable emphasis in future procurements. The problem of producing and integrating the many specially designed components plus the fact that design experience is limited, is calling for a more active relationship among the various participants. It is well known that nothing helps to put things in perspective so much as a look at one's supplier's shop and talk with his people. Industry is finding visits to the vendors' plants increasingly valuable as it provides an excellent opportunity to pass along much needed information. It is particularly desirable that these second and third tier suppliers have a full appreciation of the part which their products will play in the over-all system and the technical problems involved in obtaining satisfactory final compatibility with other components or systems. In addition to these changes in our way of doing business, today's complex products have also had a significant impact upon the quality problems being experienced.

The dependence of our latest weapon systems upon the complexities of electronics is great. Electronics, without question, has increased the capabilities of modern weapon systems because without it a workable missile would still be far in the future and Explorer I would still be in the province of science-fiction. These increased capabilities, however, have been made possible only at the cost of great increases in complexity. A ballistic missile, for example, contains from 10,000 to 300,000 separate components depending upon the particular missile in mind and the degree of breakout made. The total lead time necessary for the development and production of missile and space systems today is determined - not as it was during World War II or the Korean conflict by airframe requirements - but by the time required to develop, produce and integrate the mass of electronic gear. Electronics alone represents a greater investment in time, engineering effort and money than did the entire aircraft of World War II. For every airframe and propulsion problem there will be hundreds of electronic systems problems. This increased complexity, naturally, complicates the job of logistics support.

The impact of unmanned systems is also particularly significant from a quality control standpoint. In the past, highly trained flight crews have been an integral part of the weapon system. During flight, this human element was in many cases able to adjust for slight variations in equipment or in some cases for outright equipment failure but the luxury of this compensating factor to correct for imperfections is no longer available. It is a grim fact that at the critical moment there may be only one chance to push the button. A second missile or an anti-missile-missile, in case the first one fails, may not be possible. The reliability and precision requirements of these weapons and the magnitude of the quality problems they present is a challenge to modern quality control systems. The need to integrate all activities which have a bearing upon quality is challenging the status of Quality Control Departments in many organizations.

The most precious commodity available today is time. This resource must be conserved at all costs. In this environment the genesis of any modern quality control program must be in the design stage of the weapon. All too often this fact is ignored at the cost of redesign during the production or modification during use. It is important to note that many design deficiencies are not just "state-of-the-art" design problems but are common errors that could have been prevented by more effective control during the design and engineering stages. To alleviate these deficiencies, the effective review of design by competent technical personnel is needed to weed out those obvious errors that so frequently arise. In addition, more emphasis must be placed on the design and specification of component tests to assure early detection of unsatisfactory performance. Careful scrutiny of designs to assure that tolerances are realistic and permit economic production in the plant and maintainability in the field is becoming a must. The required performance cannot be acquired from a poor design by merely specifying unrealistic tolerances. Much can be accomplished in this area and study on improved methods and techniques is required.

The importance of a metrology engineer, as a member of the design team is daily becoming more apparent. This technical capability on the design team would assure

that design tolerances are realistic and permit economic production in the plant as well as maintainability in the field. There are field calibration requirements at the present time which exceed the present "state-of-the-art." Fortunately, past experience with similar problems has shown that many calibration requirements can be reduced both from the standpoint of accuracy and the number of individual calibrations. In the missile program, we find that a considerable portion of the maintenance workload involves calibration. This is not only because of exotic accuracies and the large number of calibrations; but a major factor in this workload is the inaccessibility of calibration points. An example of this is one of the missile support systems which has numerous pressure gauges so installed in the system that LOX clean lines must be cut, the gauges removed and calibrated, and then welded back into the system. It is quite obvious that much more consideration should be given to the accessibility of equipment for calibration in future design.

As a result of the many difficulties being experienced in providing calibration support, Amendment 2 to Specification MIL-D-9412C (USAF) has been developed which requires contractors to give adequate consideration to calibration requirements for the weapons/support system early in the development cycle. This identification must include the peculiar test equipment to support the weapon system, the common test equipment to support the peculiar test equipment; the standards required to support the common test equipment; and all the calibration data required on each piece of equipment listed. This identification will provide the Air Force an opportunity to evaluate and assure the calibration maintainability of the system during design. Past experience has shown that this procedure will pay large dividends if accomplished prior to production.

Surprising as it may seem at this point in time, there are still some activities - both Air Force and contractor - who are reluctant to calibrate test equipment used for research and development. This is difficult to understand because the adequacy of design cannot be measured unless there is some certainty as to what is being measured. If the data generated are to be of any value, the accuracy of the test equipment must be assured. Instrumentation, in reality, is the intelligence gathering tool of research which separates fact from fiction. We have recommended to the Research and Development Command that they include the requirements of Air Force Specification Bulletin Nr 520 in all future R&D study contracts.

In the production process there is a dire need for more gauges that measure, indicate, record, and control. The chemical industry is quite advanced in this respect but the machine tool industry has been slower to move in this direction. Maybe this is because the chemical industry is younger and has developed its instruments after the machine tool builders had stablised design. To effectively control quality during production, more and more of the tools must have automatic control features. This may require a look past many of the conventional methods of production measurement and search for new; maybe radically different types of measurement. The non-destructive testing field seems to be a very fertile area which can be applied to this problem. It is certainly a fertile area that deserves future research.

A new link in the quality chain in recent years is the installation and check-out phase of the missile sites. The quality problems experienced at these sites are unique in that these operations present a completely different atmosphere. The same degree of control must be exercised in a heavy construction atmosphere as is exercised in the factory environment. This problem of maintaining control is enhanced by such factors as remote locations, widely dispersed areas, and high labor turnover.

Many of the major problems stem from personnel as so often happens. The Air Force as well as contractors, is faced with difficult manning requirements for the next few years. Since these positions are of a temporary nature with high cost housing, and poor school facilities, it is difficult to recruit qualified personnel for site employment. In some instances, contractors have been able to offer pay inducements but in many cases they have had to resort to hiring inexperienced or partially qualified people from the local areas. This, of necessity, has resulted in less than an optimum operation.

To add to this problem of exercising control in the installation and check-out phase, it was soon found that much of the quality control effort had to be dispersed to other areas. Many interface problems existed between site construction and installation and check-out of the missile. Much time has to be expended in pre-acceptance inspection of facilities to get correction prior to acceptance of structures. From these experiences, it became apparent that the Corps of Engineers which by tradition was construction oriented needed to integrate their procedures with Air Force and

contractor quality control systems. Such problems as incomplete power conduits, improperly placed piping obviously will present problems during the check-out period. Another problem that hit with terrific impact was the control of cannibalization. Past experience at Vandenberg and Patrick Air Force Bases have shown that rigid control pays dividends.

We started by discussing some of the changes that have taken place in quality control and have reflected some of the challenges we face today. In the February 1961 issue of "Industrial Quality Control," Dr Juran, quite aptly discussed some of the perils facing Quality Control Departments which continue to exhibit technique orientation rather than problem orientation. Along this line, let's briefly discuss the Air Force's decision to cease formal certification of processes, equipment and personnel in such areas as heat-treating and plating. There were many signs that indicated the system had become technique oriented. It was found that these certifications were giving a false feeling of security to the purchaser as complete reliance was being placed upon the system. Users, were by contract, responsible to ascertain compliance to specification requirements; yet, Air Force certifications in many cases were being accepted at face value. These certifications, unfortunately, had assumed a routine day-to-day administrative atmosphere involving considerable paper shuffling and served little value from a quality control standpoint. There were indications that the rush of technological advances had overtaken the system and these processes needed to be placed on the same basis as other subcontractor supplies and services.

In conclusion, there is an area of quality control that has been generally overlooked which could contribute much to the quality and reliability demanded today. It will be recalled, historically, that craftsmen existed not too far in the past. These individual craftsmen made the entire item and its perfection was a measure of his skill in which he took great pride. There followed in succession the period of foremen quality control, inspection, and statistical quality control, aimed at controlling product fabrication in the plant. Gradually, more and more control was added to incoming material. To round out the quality control program the preventative aspects were recognized and the design function was added to arrive at what is commonly termed total quality control.

The many writings and discussions on total quality control have left out a very important function, which for lack of a better term, will be called operator quality control. Nothing is to be gained if we carefully control design, without making certain of the skill of the operator. Current problems attest the fact that a coordinated program of personnel quality control has often been lacking to a considerable degree. It has been found that quality control needs engineers in addition to its technical personnel and professional people to accomplish tomorrow's quality control job. Likewise, it might be equally profitable to have a personnel or training specialist aboard because company policies on hiring, transferring between jobs, promotions, and changes may not be conducive to a quality product.

In the 60s the quality control loop must be closed. We have looked much too long for a system to substitute for the skill of the operator. The craftsman must be re-established as the Keystone of the quality control system. Quality control methodology and reliability techniques must be adjunct to the development of the operator – not a substitute for his accepted deficiencies. Our professional and engineering quality control personnel must be organized to support the operator in the design and development phase. We can best assist the production process by clarifying the intent of each requirement and including only realistic requirements in the product specifications.

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NAVY PROGRESS IN QUALITY CONTROL AND RELIABILITY IN 1960

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Chief of Naval Material
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I appreciate this opportunity to talk to you about a subject of mutual interest and importance -- the progress being made by our country's Military-Industrial team in achieving a satisfactory and not too costly quality control program for the military's varied and multitudinous purchases. I hope to give you some of my own impressions as Manager and Administrator of the Navy's Material Inspection organization, rather than discussing technical problems which are adequately covered in the agenda of your Association's Annual Meeting.

We believe the steps we have been taking in the past several years to improve our overall concept of quality control continue to show their basic worth. While I know all of you are thoroughly familiar with these steps, I would like to point out a few of the more important. The principal one is, of course, the continued highlighting of the fixed and firm responsibility of our contractors to assure, prior to their submission for Government acceptance, that the supplies and materials being furnished conform to contractual requirements. Another major step is our decision that the objectives of a sound military Quality Control System are achieved more effectively by collaboration with, rather than by duplication of, similar activities in Industry. And, finally, I want to mention the dual goals of our own managerial efforts in the field of quality control. These are not only the prevention of defective material from entering service, but also -- and of equal importance -- the obtaining of better material at lower prices.

We need both better and cheaper components for our ships, airplanes and weapons if we are merely to keep up with the understandably insistent demands of the operating forces for increased capabilities in the tools of war with which they are equipped. Likewise, the rapid technological advances of our current world, which, of themselves, make these increased weapon capabilities possible, continue to result in greater complexity and cost. While I realize these are oft-heard statements used variously for many purposes, including excusing our own shortcomings, this state of affairs actually exists and is something with which we must live in increased harmony if the Armed Services are to carry out their basic missions.

To do this, we must reiterate in all appropriate forums the fact that improved quality assurance for all materials must continue to be a Joint Military-Industry responsibility necessitating cooperative efforts and attention at all management levels. On the whole, our suppliers have succeeded in the past year in finding effective measures for improving quality control systems. They have reappraised the standards and qualifications of personnel, established educational programs, reviewed quality control techniques in manufacturing and inspection methods, taken more immediate corrective actions resulting from feedback data obtained from the users of their equipment and materials, and, finally, have placed tighter control on materials purchased from subcontractors. The Navy in turn can -- and is anxious -- to help industry improve the overall Quality Control System. To do so, we are striving to improve the technical capabilities of our inspection personnel. Engineering staffs are being established in all General Inspection Offices. We have also increased the use of graduate engineers in our Quality Assurance activities. Personnel with appropriate academic background in the physical sciences are being recruited. In these ways, we are trying better to prepare our agencies to assist you in this important manufacturing function.

Let me cite a few examples which have recently come to my attention which illustrate our current quality assurance concept, the Military-Industry cooperation needed to attain maximum results, and certain recurring problems.

As you know, the Navy purchases paint, enamels and lacquers for all Military services. In accordance with our basic principle, to which I have alluded, the paint manufacturer is required to maintain an effective and economical quality control system. This covers receipt, handling, storage and testing of ingredient materials; methods and processing equipment; and procedures, controls and equipment for conducting tests.

Government acceptance of product is now based on the supplier's records of his own examinations and tests, with the Naval Inspector providing system evaluation, monitoring, and a minimum of actual production verification. The Government laboratories, which formerly did routine acceptance tests, now are utilized only for random verification of the results of the supplier's own tests. This procedure gives us a dividend in that the Government laboratories are now freed to fulfill better their basic research and development missions.

Let us now turn to a different aspect. Here a manufacturer had no quality control system to speak of, and was apparently opposed to installing one. As a result, this company, which was providing ordnance parts, was having extreme difficulty in controlling dimensions. In spite of several specification waivers that had been granted, rejections at his plant were exceeding 20%. User activities bitterly complained, partly because they did not "get the word" on the waivers, and partly because inspection at the manufacturer's plant had not reduced defects to an acceptable minimum. As a result of all this trouble, the supplier himself was losing money. More importantly, from our own point of view, Navy costs were increased by delayed material deliveries and by the necessity for detailed inspection of the supplier's material at our own plants in order to avoid working on defective material. The causes for all this trouble were finally located in the supplier's foundry which was producing non-uniform and often excessively hard castings. These were difficult to machine within acceptable tolerances and also caused unpredictable tool wear. The manufacturer finally agreed to try more effective quality controls first in his foundry and then in his machine shop. Scrap production is now 2/3 lower; the supplier is making a profit, and is a satisfactory producer for the Navy.

Now, let's consider a supplier who, while having a quality control procedure, had not taken the necessary initiative to make it work. This contractor was making a vital component for a high priority project. Close inspection revealed errors in some elements. Poor manufacturing quality control was nullifying a generally good engineering job. Upon our request, the supplier instituted some corrective measures. Subsequently, the supplier's improved quality control system was evaluated but numerous procedures were still deficient. This time, the supplier was advised of specific deficiencies in inspection methods; personnel and training; control of purchased material; use of feedback data; qualification for special processes; and non-conforming supplies. Continuing deficiencies of this type and evidence of poor product quality are still adversely affecting this supplier's relations with major contracting offices - Navy and primes. We have hopes, however, that further mutual cooperation between the contractor and ourselves will finally achieve satisfactory performance.

Let me touch briefly on reliability -- the basic purpose of quality control. Reliability requirements cannot remain static, but must be continually reviewed, based on operational experience. In addition, we must encourage and increase the interchange of reliability data among manufacturers and within the Military. I was happy to hear recently that the Services are effectively interchanging parts test data among ballistic missile manufacturers and the Services. This is excellent and should be expanded. Perhaps greater use of reliability incentives in contracts would be an added inducement to suppliers. I don't know, but I will have to look into this matter some more.

As you know, we have increased our use of value engineering incentives in contracts, realizing the important contribution that design simplification can make to lower costs and to increase quality and reliability. We have many examples of this. An important one that comes to mind is the Navy's new amphibious assault ship which can launch helicopters and landing craft simultaneously. A new type of ballasting system, using gravity and air, has eliminated pumps and markedly simplified the piping system. This design improvement saved one and one-half million dollars on three ships. The new system is faster, more easily controlled, simpler, and more reliable. Another example is an anti-submarine rocket launcher, where after taking a good look at the initial design, twenty-five per cent of the parts were eliminated from the control panels. The redesigned panel is less complex, more reliable, more functional, and easier to maintain and operate. In addition, costs were reduced seven hundred and fifty thousand dollars. I also heard recently of a seven dollar diode used to protect a transistor circuit in a component for the Polaris Submarine that has

been replaced by a more reliable resistor costing five cents. We have only scratched
the surface in areas like these. Both Industry and the Armed Services must give
greater attention to value analysis, especially during design.

     Gentlemen, I would like to leave one last thought with you. You are on the
firing line, where production is taking place. You must daily see improvements we
can make in our material inspection practices. Please let us have any suggestions
you may care to offer. It is only through our joint efforts that we can become
more efficient inspectors. If you have suggestions or complaints on how we admin-
ister the Material Inspection Program, drop me a line - I have a willing ear and
will recommend for adoption any reasonable suggestion which improves our products,
lowers our expense of doing business, and increases the amount of quality material
entering the Fleet -- material we badly need to accomplish our job.

QUALITY CONTROL-THE EVOLUTION OF AN OCCUPATION

How the shift in the Government's quality control program changed the job
requirements of Federal employees

By William R. Collins, U. S. Civil Service Commission
and
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The purpose of this paper is to report recent developments and trends
in quality control in the Federal Government, the new skill requirements
created thereby, and the formulation of personnel standards for positions
affected by the resulting program changes. The positions affected are of
a new kind, have a new purpose, and to some extent displace traditional
inspection positions.

In this age of increasing complexity many occupations are undergoing
drastic changes. Therefore other program managers and personnel or other
staff officials faced with a need for a major redirection of the skills of
personnel to function properly in a situation transformed by a change in
management environment may find a special interest in the facts presented.
The general reader also may find that it provides a case history that is both
timely and illustrative of the impact of modern technological advancements
on our daily lives.

INTRODUCTION

Recognition of the need for the creation and development of sweeping
changes in an occupation seldom occurs as an isolated action. On the con-
trary, it usually represents a gradual recognition by many people that
cumulative changes in policies and practices have significantly transformed
the basic program thus creating a need to reevaluate personnel skill require-
ments. So it evolved in the field of inspection in the Federal service.
Personnel recruitment and retention problems became increasingly difficult.
Ingenuity in making the existing personnel structure function satisfactorily
in a changed environment was taxed to the utmost. Eventually the conclusion
was reached that it was no longer possible merely to continue reorienting
traditional types of inspectors to do the job. Management became aware of
the need to do a major overhaul of its thinking about personnel needs for
these jobs, rather than to continue trying to do additional patchwork to
modify the existing structure.

The new occupational standards for Federal positions in the Commodity
Quality Control, Inspection, and Grading Group were developed by the Civil
Service Commission with the cooperative efforts of the subject matter experts
and personnel specialists in the agencies. These standards typify the
beneficial results of timely recognition of the need to study jointly the
effects of fundamental program changes upon the employee skills and knowledges
required to perform new functions.

EARLY DEVELOPMENTS IN QUALITY CONTROL

Quality control encompasses all the techniques and procedures utilized
during design, development, production, storage, maintenance and operational
use to assure that quality is first built into a product and is then held at
a suitable level for accomplishment of the product's intended use. The science
of quality control is of very recent origin. Quality control principles
developed during the 1920's were not accorded widespread application until
World War II created an urgent need for more efficient methods of production.
Since then, quality control has attained nearly universal recognition both
in Government and industry. It originated in the United States, but its
applications are now worldwide. The rapidity of its emergence has been limited
only by the availability of trained personnel capable of applying the new
techniques.

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NEW SKILL DEMANDS

The application of quality control methods requires a combination of capacities and skills seldom previously demanded of a single individual. Quality control requires its practitioners to possess and utilise a combination of technological, mathematical and administrative abilities all at an advanced level of accomplishment. To develop in the Federal service the type of staff required to apply quality control principles, it was necessary to create the proper balance of skills by recruitment from among the established career fields. In the early stage of quality control in the Government competent technologists, mathematicians, and administrators were brought into the program. In rare instances, individuals were discovered who possessed two, or even all three, of these qualifications. These individuals with a combination of diverse experience were helpful in providing a bridge of communication among other individuals with totally different and highly specialized orientation and background.

Usually the new employees were introduced into organizations which formerly were staffed preponderantly with traditional inspectors. Frequently, these new employees were graduate chemists, physicists, engineers, food technologists, and the like, who had sufficient mathematical training and analytical ability to permit their ready conversion to quality control specialists. Most inspectors who had been employed prior to the advent of quality control evidenced trade or craft skills of a high order, but many did not possess extensive education or analytical capacity. However, many of these inspectors were trained to utilize simplified quality control methods under proper guidance, although they continued to perform inspection duties which primarily required trade or craft skills.

QUALITY CONTROL PERSONNEL STANDARDS FROM THE SUBJECT MATTER POINT OF VIEW

Prior to 1958 there were basic differences in viewpoint among the Federal agencies and among the various inspection organizations within the Department of Defense regarding the underlying principles and practices that constitute an efficient and effective inspection and quality control program. These diverse views were reflected in variations in the kinds of programs which existed in the inspection and quality control organizations. It is readily understandable that significantly different personnel requirements were needed for the accomplishment of those extremely divergent programs which ranged from those restricted to the simplest kind of visual product inspection to those incorporating the most highly developed and refined quality control techniques. However, since 1958 the Department of Defense promulgated a comprehensive set of policies which institute uniform quality control programs and practices throughout the military departments. To a considerable extent, similar policies and practices are now being developed in the other Federal agencies. For example, quality control policies of the General Services Administration and the Department of Defense closely parallel each other. It is apparent that, with the establishment of a uniform set of basic principles and practices, agreement on the types of personnel required to carry out such programs could more readily be achieved.

Thus, in conjunction with the establishment of a uniform quality control program, the Department of Defense determined that it was necessary and timely to review quality control personnel requirements and identify changes which were needed to accomplish its mission under the new program.

The new Department of Defense policy placed responsibility on suppliers for performing required inspections and tests and for the development of systematic manufacturing and quality controls to assure satisfactory performance and reliability of equipment. The role of the Government under this policy was changed from determination of compliance primarily through direct examination of product to a one of verification that suppliers have established adequate manufacturing and quality controls and that inspections and tests have been properly accomplished. This verification of product quality

by the Government is achieved through a combination of direct product examination and review of suppliers' quality systems and records. As a result, Government and industry quality control programs now complement each other, rather than duplicate each other as in the past.

The rapid technological advancement and ever-increasing complexity in weapons were additional reasons for the Department of Defense to institute a complete reexamination of its quality control personnel requirements. These developments forced a continual increase in the level of skills required for the evaluation and assurance of product quality. Pressures for the attainment of higher reliability levels in missions and other weapons systems resulted in the establishment of more refined and effective quality control techniques. Throughout Government and industry these developments have been reflected in demands for quality control personnel with higher analytical abilities. As a consequence, the supply of personnel with advanced quality control skills seldom kept pace with the demand. Activities in educational fields and technical societies reflected these changes. Technical societies created and intensified programs to promote professional development in quality control. Some universities were responsive to the demands for the higher quality control skills by establishing curricula and granting degrees (BS and MS) in this field.

Personnel problems were also being created by the attractive offers tendered to Government quality control experts by industry and the rapid turnover in the more skilled quality control categories. This condition was further aggravated by the fact that because they are paid under different pay plans, the wage board product inspectors frequently receive higher pay than the higher level quality control specialists.*

In contrast with the deterioration in the Department of Defense position in the competition for quality control experts, defense contractors were succeeding in obtaining fully qualified quality control personnel to control and direct their programs. The disparity between the capabilities of the product inspector who usually represented the Government and the professional quality control engineer who represented the contractor in resolving mutual problems regarding defense contracts was more and more in evidence. Industry spokesmen frequently expressed concern over the need for the Government to be represented by individuals who could deal with their industry counterparts on equal terms.

Upon initiating its review of requirements for quality control personnel, the Department of Defense found that three basic personnel types were needed in its program. These were (1) production line inspectors, competent to carry out examinations and tests of products throughout the manufacturing processes and equipped with a knowledge of production methods in one or more commodities, (2) mathematical statisticians competent to design and develop sampling procedures and other statistical quality control techniques, to analyze the quality control data developed, and to take appropriate action, and (3) quality control specialists possessing advanced training and analytical skills, whose principal duties are concerned with directing, planning, and surveillance of quality control programs. In addition to a thorough knowledge of the techniques of product inspection, quality control specialists must possess competence in statistical quality control work, and in integrating activities of product inspectors and mathematicians in a total quality control program.

Estimates were made of quality control personnel needs under the new Department of Defense quality control programs, which placed upon suppliers

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* As used in this paper the term "quality control specialist" embraces all of the quality control position titles established in the standard, i.e., Quality Control Specialists, Quality Control Assistant, Quality Control Representative, and Quality Control Director.

the responsibility for making inspections and tests and installing manufacturing and quality controls, to assure the quality and reliability of their products. Following that, a review of the staff employed at that time indicated that there were sufficient numbers of product inspection personnel and mathematical statisticians to complement the work of the technical quality control specialist types capable of adequately performing the newly reoriented quality control function. In view of the possible effects of the shortage on the successful execution of the new program, serious consideration was given to delaying the promulgation of unified Department of Defense policy covering suppliers' inspection and quality control systems. It was clearly evident that the new program could not be accomplished properly by relying solely on the personnel then in the system. This was no reflection on the capability of the trade and craft type inspector to do the job for which he was hired. After all, product inspection did not take a high degree of managerial and analytical ability. The inspector who could determine that steel thickness, as measured by a micrometer, was outside tolerance limits could not be expected, solely on the basis of the craft skill for which he was hired, to evaluate control procedures nor to explain to a contractor's management staff his reasons for deciding that the control procedures were unacceptable. To have demanded such abilities as a prerequisite for conventional product inspection work would have been totally unjustified.

Despite these important considerations, it was determined that the unified policy should be promulgated, but that in recognition of the shortage of qualified personnel, sufficient time would be allowed for transition to the new methods to permit the recruitment and training of qualified personnel.

Another urgent consideration which had to be weighed carefully in establishing the training and in setting the speed of this conversion was its possible effects on inspectors then on the job. Although it was evident and clearly desirable that the new program would result in greater efficiency, calling for fewer but better people, it was imperative that the conversion be accomplished in such a manner that reductions in force would be avoided, in full compliance with Department of Defense policy. However, the fact that the average age of on-board inspectors was high, with many approaching retirement, could be counted upon to ease the situation.

THE STANDARDS FROM THE PERSONNEL POINT OF VIEW

The situation discussed above was further complicated by the fact that, historically, in Federal employment there have been a variety of pay systems. Two main ones have been the system applicable to Classification Act positions which, broadly speaking, are white collar jobs and the ungraded or wage board pay system applicable to blue collar jobs. Pay for the former is specified in the Classification Act in the form of a pay range applicable to each "grade." Each "grade" or level is defined in the Classification Act in terms of difficulty and responsibility. Salary rates applicable to each grade are the same regardless of geographic location. Except for modification in order to hire for positions in shortage categories at pay rate steps above the minimum for the grade, salary rates for white collar jobs can be changed only by Act of Congress. By contrast, pay for wage board jobs is--generally speaking--set by the employing agency based on the prevailing rates being paid in private industry in the locality. Levels for wage board positions are not set by Congress. There are many fine points involved in defining the coverage of each of these major pay systems. However, precise distinctions need not be made for the purposes of this paper. Generally speaking, the Classification Act applies to white collar and professional positions while the wage board system is used for trade, craft and laboring positions.

For many years (including those of World War II) practically all positions in the inspection programs of the Federal Government were of the Classification Act type and were paid Classification Act salaries. Following World War II, however, many Federal agencies began placing emphasis on

recruiting skilled craftsmen and tradesmen to staff inspection positions.
In part this trend arose from a conclusion on the part of the agencies
that end-product inspection required the same types of knowledges and skills
as those required to Fabricate the product initially. In part, however,
this trend also received impetus from the fact that higher wages could be
paid under the wage board system and these facilitated recruiting. In addi-
tion, the Congress had imposed a "ceiling" on the number of Classification
Act positions in certain agencies but had not similarly limited the number
of wage board positions. There ensued so much confusion as to the appro-
priate pay category of inspection positions that the Civil Service Commis-
sion, in 1952, responded to agency requests for clarification of the pay
system determination by issuing specific instructions and criteria for
making this type of decision. Those instructions emphasized that the factor
which would determine the pay system for any position would continue to be
the nature of the qualifications required to do the work.

The Commission's instructions could not, of course, eliminate or even
alleviate, the salary and numerical ceiling pressures which continued to be
pressing. It is very probable that many of the decisions on pay category of
individual positions which were made in those years were influenced more by
the salary and ceiling issues than by the more pertinent criteria of quali-
fications required to do the work. Ultimately, the confusion surrounding
the pay category of inspection positions of the traditional variety was
joined by the problems of adapting inspection programs to the quality control
concept. The incongruous result was that jobs were being ungraded and crafts-
men were being hired to fill them at the very time when the needs of the
inspection programs for a different type of personnel were increasing.
Small wonder it is, then, that problems arose in staffing the more modern
quality control programs which ranged on the one hand from application of
statistical sampling techniques to end product inspection (representing a
special phase of quality control), to, on the other hand, a very broad appli-
cation of the full range of quality control principles and techniques during
the entire life cycle of the commodity, equipment, or process.

In the latter part of 1958, at a time when the agencies had pretty much
identified the program changes to be made, Mrs. Mary E. Whelan of the Civil
Service Commission's Regional Office in Cincinnati was assigned by the
Commission to make a study of the occupation. The purpose of the project
was initially to deal with and produce position classification standards and
qualification standards for only a relatively few positions in the inspection
group. Other types of positions in the group were to be covered later.

At the invitation of the Civil Service Commission, the Department of
Defense and other agencies participated actively in the development of the
standards. This not only permitted but also encouraged and speeded a review
of the impact upon personnel requirements of the fundamental changes in
the quality control program. This study required intensive joint effort by
agency quality control and personnel managers.

The Department of Defense established task groups to study various
aspects of the problem. Personnel and quality control managers in the Army,
Navy and Air Force, and within the Office of the Secretary of Defense parti-
cipated. Counterpart staff representatives in the General Services Adminis-
tration and other interested Federal agencies were informed of the work of
these groups, and cooperated in the formulation of the standards.

Four months of factfinding included travel to many Government installa-
tions and industry facilities. Among the activities visited were those of
Army, Navy and Air Force in the Department of Defense, General Services
Administration and other non-military agencies. A greater amount of time was
spent in the military services since the largest proportion of Federal
employees engaged in this work are Department of Defense personnel.

Information gathered during the factfinding revealed that partial
treatment was impractical. Therefore it was determined to enlarge the
scope of the project to formulate a single master standard applicable to the
entire inspection occupational group (with certain limited exceptions).
This was based on the conclusion that a common core of knowledge require-
ments, duties and responsibilities that permeated the entire group had been
successfully identified. The distinctions that marked the specializations
in the group were commodity knowledges that served to identify differences
in kind of work and knowledges required. However, elements which affect
the levels of difficulty and responsibility were similar from one commodity
specialization to another.

One of the major conclusions of this analysis was that quality control
represented a major career field. Product inspection was recognized to be
an important element of quality control but to constitute only one phase
of the overall quality control program.

The standards in existence at the time the study was launched consisted
of a loosely related collection of standards applicable only to conventional
inspection type jobs. Numerous problems were involved in attempting to
develop a completely integrated coverage for both those inspectors and the
more demanding quality control specialists. Those problems extended to
(1) what commodity specializations needed to be identified, (2) how the
internal series structure should be organized, (3) whether the several
functional specializations (e.g., those for inspectors and quality control
specialists) should be in the same series or in parallel series, and (4)
how the title structure should then be established.

On the basis of this study, the Standards Division of the United States
Civil Service Commission developed a complete proposal for review and comment
by the Commission's regional offices and the Federal agencies. Upon
receiving these comments, the Standards Division undertook to evaluate
the comments, to reconcile differences in points of view. In many instances
the differing reactions stemmed from variations in the degree to which the
quality control program had been implemented in various organizations. In
the main, the reaction was favorable although many changes were suggested.
Nevertheless, some agencies expressed dissatisfaction with the proposal.
Careful consideration was given to the opposing points of view. Upon
assessment of all the comments and incorporation of constructive suggestions
and changes based on valid criticisms, it was decided that issuance of the
standard as an official document would be a sufficient improvement over the
existing standards to proceed without delay.

One of the important objectives in the preparation of the standard was
to improve the criteria for distinguishing between Wage Board and Classifi-
cation Act inspection positions. A thorough and comprehensive set of dis-
tinguishing criteria was established in the new standard. No flat and
arbitrary rules were laid down. However, it has been generally recognized
by quality control and personnel officials that these have been made as
specific as they can be. Basically the guidelines provide for and require
thorough analysis and judgment prior to arriving at a decision regarding
coverage. The nature of the work, the qualification requirements, the type
of program to be carried out, which in turn determines the skills and know-
ledges required, significantly influence the ultimate decision.

In addition to the classification standard which covers the evaluation
of the kind of work and the level of responsibility and difficulty, the
Civil Service Commission developed a new qualifications standard which sets
forth the skills, knowledges, abilities, and other qualities required to be
eligible for these positions. As is now customary, both the classification
and qualification standards for quality control and inspection positions
were developed at the same time and by the same standards writer. The under-
lying premise of the qualification standards was based on the demonstrated

evidence that quality control personnel must have skills, abilities, and
knowledges over and beyond those required of inspectors and inspection
specialists. It was recognized that there would be a major problem in
selecting, training, and converting those inspectors who could meet the
higher requirements of the new quality control assignments when the shift
in the program and operations was accomplished. In view of the differences
in the job demands, it was necessary, therefore, to establish one qualifi-
cation standard for the quality control type position and a different one
to cover the inspection type. It was also recognized that although the
ungraded type of inspection work is acceptable experience for the graded
inspection positions it is not qualifying for quality control positions.

A major source of recruitment for quality control positions was
expected to be from among college graduates or applicants with experience
who qualify under the Federal Service Entrance Examination. The Federal
Service Entrance Examination is a very broad examining vehicle used to fill
entrance-level positions in a great variety of management, administrative,
investigative and professional occupations. In lieu of requiring Federal
employees already in Classification Act inspection positions to pass the
written test for the Federal Service Entrance Examination, the standard for
quality control positions provides for and encourages the development of
agency programs designed to screen and train inspectors in order that they
can qualify for the new quality control positions.

ASSESSMENT OF PROGRESS AS QUALITY CONTROL MANAGEMENT SEES IT

In the opinion of quality control program managers, the Civil Service
Commission has been successful in constructing a standard which is fully
abreast of the times and adequately reflects the present state of develop-
ment in the field of quality control. The standards reflect advancements
in product complexity and quality assurance technology which have occurred
in recent years. They provide a suitable progression in levels (and permit
the establishment of increments in salary compensation that give proper
recognition to the higher skills). The standards facilitate recruiting
urgently needed personnel with higher potential and skills. At the same
time, they permit the conversion of experienced on-board employees who
have suitable qualifications to the new quality control positions, and reten-
tion and utilization without undue dislocation of those who remain inspectors.
The continued existence of some inspection positions under Classification
Act coverage provides an additional benefit by serving as a buffer to protect
seasoned personnel who may not qualify for the new occupational specialty,
or who may not convert for other reasons.

But to the quality control program manager, the principal achievement
of the new standards unquestionably is its recognition of quality control
as a new occupational specialty requiring a high level of abilities and
skills. Without this far-reaching realignment the task of conversion to the
new quality control concepts would have been far more difficult or else
completely impossible. Quality Control program officials believe that the
new occupational standards contribute significantly to the accomplishment
of the quality control program of the Department of Defense.

SUMMARY

A number of conclusions can be drawn from the facts that have been
presented. Both in Government and industry, quality control has attained
widespread recognition as a highly specialized technical field meriting the
establishment of one or more new occupational fields. The quality control
policies and programs of the Department of Defense, the General Services
Administration and other Federal agencies have had a significant influence
in the rapid advancement of quality control engineering and technology,
both in the United States and abroad. The new classification and qualifi-
cation standards for quality control and inspection position constitute
another significant contribution by the Federal Government in encouraging

advancements in this specialized field.

There is a widely held opinion in the agencies that for the immediate future requirements for quality control engineers will constitute only a minor proportion of the personnel engaged in quality control activities. In the Department of Defense, quality control specialists and representatives will probably constitute the major portion of its inspection and quality control staff. The number of mathematical statisticians in the quality control organizations should remain essentially unchanged. There will probably be a gradual decline in the number of wage board type inspectors, especially in procurement programs. The number of Classification Act type inspector and inspection specialists can be expected to decline to some degree in future years.

There is some difference of opinion regarding the number of professional engineers required in the quality control program, what their role should be, and what needs to be done to identify better to career patterns. In the Department of Defense professional engineers have been utilized in increasing numbers. Some quality control program officials favor a further increase in the number of professional engineers utilized in the program. Other officials favor further study of the role of the professional engineer in the program and also a continuing examination of the career opportunities available to professional engineers who are already in the field of quality control. With regard to the occupational identification of the professional engineer working in the field of quality control, many program officials agree with the Civil Service Commission's recent decision not to identify quality control engineering as a separate engineering discipline. Inherent in that decision is the concept that quality control is a specialized function which may exist within any of several of the established engineering disciplines. For example, in the position classification standard for the Industrial Engineering Series, GS-896-0, quality control is described as one subject which may involve knowledges and abilities characteristic of industrial engineering. There are other quality control program officials who would have preferred to have quality control engineering separately identified. Since quality control is still evolving, it is yet too early to predict precisely how professional engineers working in the field of quality control will ultimately be identified and utilized. Continued study of these aspects will be required of both program and personnel officials in order to keep pace with the total development in quality control.

THE JOB AHEAD

The personnel standards which recently have been developed reflect the current status of development of the occupation. Quality control is a dynamic, constantly changing program. Therefore, the demands placed upon those who carry out the quality control functions are still changing and will continue to change. It is not clear at this time what the nature of the changes will be. The immediate job ahead is the achievement of a smooth transition from the previous product-inspection-oriented to the present quality-control-oriented programs. Care and prudence must be exercised during this transition period to insure that human considerations remain paramount and that full assurance of quality of defense and other Federal materials is not compromised. The long-range job ahead is the continuing responsiveness to changes in the program which in turn will determine the ways in which quality control positions evolve.

SLICING THE PIE

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For a variety of reasons there has been recently a tremendous upsurge
in the emphasis on reliability. Some of the reasons are economic, some
relate to mission success, some relate to maintenance and logistic aspects.

Out of this upsurge of emphasis have sprung many facets of effort in
reliability. The major ones appear to be:

(1) The treatment of reliability as a measurable quantity and expres-
sions of measurement in numerical terms.

(2) Inclusion of quantitative reliability requirements in purchase
specifications and contracts.

(3) Apportionment of a reliability requirement to the subportions, sub-
systems, units and parts of a product as definitive design parameters for
these elements.

(4) Techniques, procedures and tests for demonstrating, on paper and
physically, the degree of reliability and the confidence level that have
been achieved in the product during the various stages of its genesis.

The Bureau of Ships subscribes to the utilization of a quantitative
treatment of reliability. Anytime that the technical aspects of a task can
be treated in quantitative form, the result is to minimize the variability
of interpretation amongst people working on the task.

If we look at the problem of reliability, we find that one cannot merely
specify the reliability to be achieved; one must also specify the extent to
which the achievement is to be proven; i.e., the confidence level, and the
confidence interval over which that level holds. Implicit in this definition
of confidence level and an associated interval is the assumption that there
is a sufficient combination of samples to be tested, and time for test, so
that demonstrated achievement of the specified reliability will be factual.

This approach is sound for the relatively high volume products with
mean times between failures in the hundreds of hours. It is reasonable in
terms of economy, inventory requirements, delivery schedules and other con-
siderations to expect that a sound statistical verification of product relia-
bility will be made prior to placing the product in service. This is sig-
nificant because this is what the contractor signed up to do. True, there
may be further requirements that the contractor follow the product in service
as a design improvement process, but speaking generally on this class of
product, a contractor's responsibility is to deliver a product shown to be
satisfactory by test.

At the other extreme of the technical gamut, lie those complex equip-
ments of which only a few will be produced. In addition, the desired fail-
ure-free time in operation often runs up into the thousands of hours. Veri-
fication of product reliability by appropriate combination of test samples
and test time becomes prohibitive in terms of cost and time before the pro-
duct can be placed in service.

So this then is the dilemma for the low volume product. It is obvious
that we would like to have a product with high reliability proven to a high
confidence level over a small confidence interval, but verifying fully by
test that these objectives have been reached is impractical. Tests, inspec-
• tions, reviews of subportions or even prototypes, only take us part way
towards the specified confidence level.

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How do we bridge the gap between a factual confidence level and a specification requirement? Whether we like it or not, or whether we find it sufficiently quantitative, we do attempt to bridge the gap by indirect means.

A contractor asserts that he has bridged the gap by presenting those aspects of his operation that should give the customer the necessary confidence. The contractor describes the significance of partial tests and the reliability predictions; shows the consideration he has given to problems; points out the capabilities and past successes of his personnel.

The customer evaluates the contractor's presentation. If he is convinced that the desired level of confidence has been reached, he accepts the product. If not convinced, the customer may require further partial testing; use of consultants, additional analysis.

Erroneous estimates of the indirect confidence, by either party, have serious implications. Yet the estimates are very difficult to make accurately because so many intangibles are involved.

The importance of improving the ability to estimate indirect confidence warrants full use of all approaches that will remove some variability from the estimates.

A major effort in this direction is in the development of systems to provide planned and comprehensive assurance of conformance to contractual requirements, up to the limits of physical testing mentioned previously. Quality Control Systems, as defined in MIL-Q-9858, encompass conformance in manufacturing. Reliability Programs, Reliability Assurance Systems, Reliability Control Systems, generally encompass the engineering decisions and conformance.

The display of the scope and depth of these systems, and the information derived from their use, is the contractor's mechanism for showing he has bridged the confidence gap. The evaluation of these systems is the customer's mechanism for assuring himself that the sum of the confidence level derived from test and the amount of indirect confidence add up to the required confidence level.

The use of the indirect confidence places special emphasis on the reliability of the people who in many ways contribute to the reliability of the product. What is the probability that the people; engineers, craftsmen, buyers, stock clerks, supervisors, will perform satisfactorily for a specified period of time in their physical and mental environment? This is a basic question for any production job shop. It is also a basic question for most engineering design groups, for design is frequently a job shop type of operation; each job generally having significant differences from previous work, and the number of designs done repetitively is small.

Attempts to improve the reliability of people extend over a long period. No real single factor has been found which automatically reduces the variability and unpredictibility of the actions of people. Variations are caused in engineers, in craftsmen, supervisors and fork-lift operators by many factors. These range all the way from domestic problems, to encounters with new frontiers where the approach to a problem is at best only an educated guess. It should be kept in mind that any person contributing to the product can, at any time, make a mistake which partially or completely destroys the effort and expense that has gone into building a reliable product.

The successive re-cycle of design, production, test - design, production, test - design, production, test has been the traditional method of arriving at a reliable product. However, in the areas where this is impractical, the focus must be on the reliability of the people.

There are no new magic tools which will suddenly make people reliable. Quantitative treatment and prediction of reliability are a big step in this direction. There are, however, a few tested standbys which will help to remove some of the factors that lead to unreliability and thus in the negative sense, contribute to improve reliability. These factors are the following:

(1) <u>Organization</u>. In the literature there are articles describing the functions which have been assigned to special groups such as reliability engineering, quality control or various other names. Over and over again it is obvious that if all the assignments are carried out, then the special groups are supermen; authorized to review and change designs; to contribute as part of an engineering team to reliability; to be father confessors to any reliability problem. An assignment of duty such as this makes these groups both judge and jury. It makes them authorities without responsibility. It beclouds what should be proper and clear lines of:

      (a) authority for decisions
      (b) responsibility for decisions
      (c) responsibility for conformance to decisions
      (d) responsibility for assuring that the decisions and the conformance lead to a satisfactory end product.

The lack of clear cut lines of authority and responsibility can only lead to gaps in the coverage of the problems that must be solved; to shrugging off of responsibilities because no one really knows who has it; to internal conflicts of professional and trade cognizance.

(2) <u>Physical and Procedural Environment in Which Personnel Operate</u>. The physical environment reflects the compatibility between the sensitivity of the work being done to foreign material or contamination, and prevalence of such contaminants in the areas. It is unreasonable to expect a craftsman to keep his work free of contamination when he is surrounded by dirt; when his tool for cleanup is an air hose with which to blow out chips; when the transportation of suborions of the equipment through the plant leads to exposure to dust, trash and rain. That is obvious in the production area. Less obvious in the engineering and production areas is the procedural environment. Are there current copies of Military Specifications readily available in design? Are there definitive instructions concerning the size of lettering to be employed in drafting, so that reduced size plans will still be legible? Is there a formal effort by management to make sure that the engineer, the craftsman, even the janitors, are aware that management is interested in a reliable product? Are the problems associated with reliability outlined as tasks, and assigned and ticked off so that there is a knowledge of what has been done and what remains to be done? Is there an internal agreement that vague specifications by the customer, such as "free from injurious defects" will be interpreted in quantitative terminology such as "defects less than 5% wall thickness, fair out; less than 12% wall thickness, fair out and weld; greater than 12% wall thickness, discard".

(3) <u>Analysis of Product Interfaces</u>. A lot of factors cross the interface between the contractor's product and the surroundings. Electrical power, cooling water, vibration, shock, dust and dirt, people, control signals; all enter the product from outside sources. Analysis of these inputs for completeness in regard to desirable inputs, and for undesirable inputs--indentification as problems; should make it much more likely that the designer will consider what he must do to correct for inadequate or unwanted inputs. Here again if the customer has not defined the nature and range of these inputs, there should be an internal mechanism by the contractor which will set these ranges, clearing these as necessary with the customer.

(4) <u>Recommendation of Implications</u>. As the engineering and production of a product gets more and more subdivided into numerous specialties, it becomes harder and harder for any one individual to recognize the significance

of his decisions, or work, in terms of the implications of these decisions. There is need for a formal campaign which examines the requirements coming in for a new product and singles out the new aspects. These aspects may be to use stronger steel, less humid air, nonflammable lubricants, more accurate measurements. Normally these requirements would be translated by engineering into plans and specifications. Then they would be transmitted to Production. At this time it may be learned that Production is not prepared with facilities, with training, with understanding, to meet the new requirements. There is need to point out early to all personnel just what the implications are of the new developments. In particular, there is need to provide throughout the organization an agreement on which features of the new processes or requirements must be factually proven correct; which must be proven correct to a lesser degree, and which are of such a nature that reasonable assumptions about their correctness are sufficient. In this same connection, magazine articles and presentations often convey the theme that the only thing that can happen to a design once it leaves the engineering group is to have it degraded by everyone else. While it is very true this is often what happens, it is also true that a good many poor designs are improved upon by production recommendations. If there is to be an overall improvement in the reliability of people contributing to indirect confidences in the product, then there must be recognition that the engineer, the craftsman, the stock clerk, the truck driver, the contract man are each links in this total network. Assertions of superiority by any one group can only lead to the attitude by others, "if they're so smart let them figure out what to do about this mistake they made."

The procurement dollar is often presented as a pie, with slices of this pie apportioned to the many places. In cutting a slice for reliability, particularly for the low volume, long MTBF products, there must be a share saved for those areas that are important to improvement in the reliability of the people creating the product.

The opinions or assertions contained therein are the private ones of the writer and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

WHAT'S THE DIFFERENCE?

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INTRODUCTION

The technique presented in this paper is simply a graphical interpretation, based on testing differences between means, for a standard 2^3 factorial with replication design. It has the unique advantage that its conclusions can be represented visually in a form close enough in appearance to a control chart to be easily and meaningfully understood by anyone familiar with the control chart concept. This is an important advantage because it serves to simplify the sometimes difficult task of communicating to production and plant personnel not familiar with the meaning of formal experimental designs the practical interpretations buried in these designs. In addition, this graphical technique has the attractive property of being easy to formulate and fast to carry through in a wide variety of actual production situations.

STRATEGY AND DESIGN

The ingredients needed to make the technique applicable are:
(1) A problem which the people concerned can agree involves one dependent (or "response") variable and three independent variables (or "factors") each of which can be replicated at two levels. The independent variables would be called "main effects" in experimental design. They (and the levels chosen for them) must be agreed on prior to setting up the shop (or laboratory) situation for getting the data, and they must be variables (and levels) of practical importance.
(2) Facilities must be available (and strict supervision exercised) to make sure the data are really obtained as required by the design.

The design (or "blue-print") for getting the data may be laid out as shown in Figure 1. This is clearly a straightforward 2^3 factorial design. Numbers in parentheses merely serve to give cell identification for describing the analysis procedures to be followed.

	Factor 1	Level 1		Level 2	
	Factor 2	Level 1	Level 2	Level 1	Level 2
Factor 3	Level 1	(1)	(3)	(5)	(7)
	Level 2	(2)	(4)	(6)	(8)

FIGURE 1 - Design Layout for Getting the Data

There will be n observed values of the dependent (response) variable in each of the 8 cells, a total of 8n observations altogether. For each of the 8 cells, we shall need to compute two statistics: the cell mean and the cell range, if $n \leq 10$, or the cell standard deviation if $n > 10$. Thus $\bar{X}_i$, R_i (or σ_i) represent the required statistics for the i-th cell.

We shall want to test the 8 ranges (or standard deviations) for statistical control, and if control exists, to estimate σ'_X from $\bar{R}$ (or $\bar{\sigma}$) in the usual way, i.e. $\bar{R}/d_2$ (or $\bar{\sigma}/c_2$).

There will be 7 "comparisons" we shall want to make and exhibit graphically, each comparison being simply the difference between the mean of some 4 of the 8 cells vs the mean of the remaining 4 cells. Thus, $D_{kl} = \bar{X}_k - \bar{X}_l$ represents the kl-th one of the 7 comparisons required. Three of these comparisons will be for main effects, three will be for first order interaction effects, and one will be for the second order interaction effect.

All the observed values of the dependent (response) variable when test conditions are set up for (Factor 1, Level 1) and (Factor 2, Level 1) and (Factor 3, Level 1) are recorded in the cell labeled (1). (See Figure 1). When test conditions are set

up simultaneously for (Factor 1, Level 2) and (Factor 2, Level 1) and (Factor 3, Level 2), the observed values of the dependent variable are recorded in the cell labeled (6). Similar considerations dictate the sources from which data for the other cells will come.

The number n of observations ("replications") to be recorded in each cell will be determined by the number estimated as necessary to get the desired discrimination between any two of the seven pairs of means $\bar{X}_k, \bar{X}_1$, or it may simply be some arbitrary, convenient number which will facilitate getting the data quickly and with the minimum of interruption to routine operating conditions. In the former case, an estimate of the standard deviation of the dependent variable must be available from sources outside the actual data of the "experiment" (the "sigma-known" case). Also, in this case, the critical difference between any two comparisons ($\bar{X}_k$vs $\bar{X}_1$) which it is desired to have the experiment pick up at a preassigned level of significance must be specified. In the latter case (n arbitrary and "sigma unknown", i.e. computed from the data of the experiment), the magnitude of n is determined purely by "practical" rather than "statistical" criteria.

Suppose $\hat{\theta}_x$ is an independent estimate of σ_x', and suppose $D_{k1} = \bar{X}_k - \bar{X}_1$ is the critical difference we want to pick up with significance α. Then n may be found by solving for n in the relation $(D_{k1}) \sqrt{2n}/\hat{\theta}_x = Z_\alpha$, where Z_α is the normal deviate corresponding to a two-tail significance level of α.

After the data have been collected, calculate $\bar{X}$ and R (or σ_x) for each of the 8 cells, and make a range (or standard deviation) control chart to see if there is enough evidence of homogeneity of variances to continue the analysis. If there is serious out-of-control evidence on this chart, any further analysis is open to question and the experiment should be repeated or assignable causes sought to explain the lack of homogeneity in cell-to-cell variability--or both! If the variances can be regarded as sufficiently homogeneous, estimate σ_x' from $\bar{R}/d_2$ (or $\bar{\sigma}/c_2$) where d_2 and c_2 are the usual correction-for-bias constants used in routine control chart studies.

Next, calculate $\sigma_D = \sigma'/\sqrt{2n}$, where σ' has been estimated from $\bar{R}/d_2$ (or $\bar{\sigma}/c_2$) and n is the number of observations in each cell. Now find $\bar{X}$ for all 8 cells from $\Sigma X_1/8$ (or $\Sigma X_1/8n$) and set up what looks like a control chart with central line at $\bar{\bar{X}}$, "decision lines" at $\bar{\bar{X}} \pm h\sigma_D$, and a "sample number" scale that will provide for plotting 14 points. The value to use for the multiplier h in setting up the decision lines will depend on whether one uses σ' estimated from $\bar{R}$ (or $\bar{\sigma}$), or the independent estimate $\hat{\theta}_x$, in computing σ_D. When σ' is used, $h = \frac{1}{2}t_\alpha$ (8n-8) where t_α (8n-8) is the Student t value at (8n-8) degrees of freedom corresponding to a two-tail significance level of α. When σ_x is used, $h = \frac{Z_\alpha}{2}$ where Z_α is the normal deviate corresponding to a two-tail significance level of α. Generally speaking it will be more conservative to use the t form for h, altho a "quick-and-dirty" value that may suffice is simply h=1. If there are no border-line points, i.e. no plottings close to the decision lines that go with h=1, these lines will suffice to provide valid decisions.

Altho the procedure for completing the analysis could be described in general terms, a specific numerical example will be easier to follow. Data are from an actual case history application but have been coded, and factors and levels have been left undefined to protect source identity. Note that the two levels of Factor 3 are attribute rather than variables levels.

A CASE HISTORY EXAMPLE

Serious difficulties were being experienced in maintaining uniformity in a response variable "length" for product coming from a particular type of machine. It was agreed that among a list of factors believed to have an effect on this length variable, three stood to be sufficiently important to be worth trying in a 2^3 factorial experiment. These factors may be identified as M, W, and T and the coded values of the levels chosen are shown in Table I. Shown also in this table are the mean and range (in coded values) for each of the 8 cells; the individual observations within each cell are not shown.

TABLE I - Data for Case History Example

M	$M_1 = 135$		$M_2 = 143$	
W	$W_1 = 86$	$W_2 = 92$	$W_1 = 86$	$W_2 = 92$
T H	$\bar{X}_1 = -4.7$ 1 $R_1 = 29$	$\bar{X}_3 = 4.3$ 3 $R_3 = 24$	$\bar{X}_5 = -2.4$ 5 $R_5 = 23$	$\bar{X}_7 = -3.0$ 7 $R_7 = 37$
T S	$\bar{X}_1 = -.4$ 2 $R_2 = 16$	$\bar{X}_4 = 3.4$ 4 $R_4 = 29$	$\bar{X}_6 = -8.4$ 6 $R_6 = 26$	$\bar{X}_8 = -4.5$ 8 $R_8 = 18$

From some scattered control chart data prior to this experiment, it was estimated that if control could be maintained a σ' of about 7 could be expected. Hence, $\hat{\sigma}_x = 7$ was a "known-sigma" value. It was desired to have the experiment pick up as significant at the 5% level a difference of 4 between any two means $\bar{X}_k, \bar{X}_l$. So $Z_{.05} \approx 2$, $D_{kl} = 4$, $\hat{\sigma}_x = 7$, and we have $4\sqrt{2n}/7 = 2$ which gives $n \approx 7$. Since data were fast and easy to get from this process, n=10 observations per cell was chosen.

From the data of Table I it will be found that $\bar{R} = 26.50$, $UCL_R = 47.08$, $LCL_R = 5.91$ and variation is random within the control limits. Hence, $\sigma' = 26.50/3.078 = 8.609$, so $\sigma_D = 8.609/\sqrt{20} = 1.925$. Also $\bar{\bar{X}} = -15.7/8 = -1.9625$ and $t_{.05}(72) = 1.994$. Hence h=1.994/2 = .997, and decision lines are at $-1.9625 \pm (.997)(1.925) = -1.9625 + 1.9192 = -.043$ and -3.882. We may now lay out the chart on which we shall plot the 7 comparisons as soon as we have them computed.

To compute these comparison values, we build up tables like Tables II and III from the basic data of Table I. Plot on the chart (see Figure 2) the three main effect comparisons from the entries in the third column of Table II and the four interaction effect comparisons from the entries in the third column of Table III. In doing this, label the "sample number" points (from left to right): (1-2-3-4)-(5-6-7-8); (1-2-5-6)-(3-4-7-8); (1-3-5-7)-(2-4-6-8); (1-2-7-8)-(3-4-5-6); (1-3-6-8)-(2-4-5-7); (1-4-5-8)-(2-3-6-7); (1-4-6-7-(2-3-5-8). Join by a straight line each of the plotted points corresponding to the respective hyphenated pairs given here.

Any of these 7 lines that more than spans the decision lines on the chart represents a comparison between the two levels of the associated effect represented by the line that is significant at the 5% level, i.e. there is a 1 in 20 chance that we will be claiming as significant a difference that is actually just an unusual sampling variation. Conversely, any of these 7 lines that fails to span (is included entirely between) the two decision lines represents a comparison that can be regarded as a sampling variation. We shall not try to pin down the magnitude of the Type 2 error committed by this latter decision, but it is of the same nature as the decision we regularly make to "leave the process alone" when points fall within control limits on an ordinary control chart.

The completed comparison chart (Figure 2) shows that none of the interaction effects are significant at the 5% level, but that the two levels of factor M are highly significant and that the two levels of factor W are also significant.

COMPARISON WITH ANOVA

If we take the data in Table I and run a standard analysis of variance for a 2^3 factorial with replication, we will obtain the results shown in the Anova Summary Table exhibited as Table IV. Note that the conclusions are identical, viz no significant interaction effects, but factors M and W are significant as main effects, with M showing significance at the 1% and W at the 5% levels respectively.

TABLE II - Averages for Main Effects Comparisons

Factor	Level	Cell Numbers	Average Required
M	M_1	1-2-3-4	$\bar{X}_{M_1}$ = 0.650
	M_2	5-6-7-8	$\bar{X}_{M_2}$ = -4.575
W	W_1	1-2-5-6	$\bar{X}_{W_1}$ = -3.975
	W_2	3-4-7-8	$\bar{X}_{W_2}$ = 0.050
T	H	1-3-5-7	$\bar{X}_H$ = -1.450
	S	2-4-6-8	$\bar{X}_S$ = -2.475

TABLE III - Averages for Interaction Effects Comparisons

Interaction	Cell Numbers	Averages Required
MXW	1-2-7-8	$(\overline{MW})_1$ = -3.150
	3-4-5-6	$(\overline{MW})_2$ = -0.775
MXT	1-3-6-8	$(\overline{MT})_1$ = -3.325
	2-4-5-7	$(\overline{MT})_2$ = -0.600
WXT	1-4-5-8	$(\overline{WT})_1$ = -2.050
	2-3-6-7	$(\overline{WT})_2$ = -1.875
MXWXT	1-4-6-7	$(\overline{MWT})_1$ = -3.175
	2-3-5-8	$(\overline{MWT})_2$ = -0.750
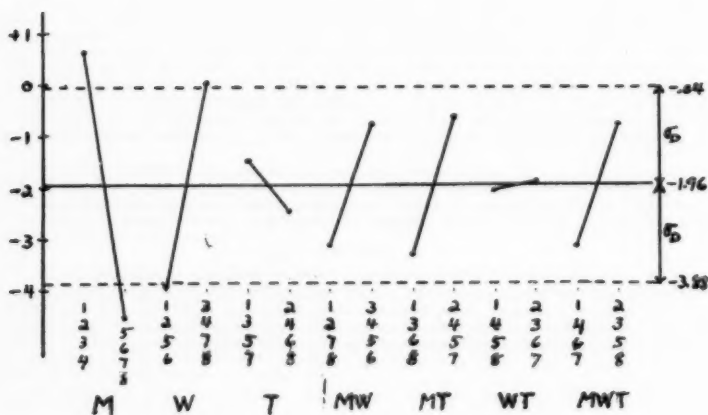
FIGURE 2 - Comparison Chart for Data of Tables I-II-III

TABLE IV - Anova Summary Table for Data of Table I

Source	Sum of Squares	d.f.	Mean Square	F_0
M	546.01	1	546.01	7.64**
W	324.01	1	324.01	4.53*
T	21.01	1	21.01	$F_0 < 1$
MxW	112.81	1	112.81	1.58
MxT	148.51	1	148.51	2.08
WxT	0.61	1	0.61	$F_0 < 1$
MxWxT	117.61	1	117.61	1.64
Error	5144.32	72	71.45	
Total	6414.89	79		

$$F_{.05}(1,72) = 3.97 \; ; \; F_{.01}(1,72) = 7.00$$

Note also that the error variance in Table III gives $\hat{\sigma} = \sqrt{71.45} = 8.45$ vs $\bar{R}/d_2 = 8.61$. (If standard deviations per cell in Table I are used, it turns out that $\bar{\sigma}/c_2 = 8.49$ which is even closer to the anova estimate of 8.45.)

Thus the graphical analysis and the standard anova strategies lead to the same conclusions, but the computational details are somewhat heavier in the latter procedure and the naked F-test statements lack the sex appeal that is visible thru the graphical presentation of the comparisons involved. As a fast-moving tool that gets answers which make sense to plant personnel, this little technique is well worth a trial if it is important to know "what's the difference" without going into a full scale analysis of variance.

REFERENCES

1. "A Production Experiment Using Attribute Data"; Ennerson, Fleischmann, and Rosenberg; IQC, March 1952, p. 41. (Unfortunately there are several errors and misprints in this paper that the reader will have to discover for himself.)

2. "A Production Experiment with Mechanical Assemblies"; Ellis R. Ott; IQC, May 1953, p. 124.

3. "Use of Edge-Notched Cards in the Analysis of Variance"; Lloyd S. Nelson; IQC, April 1957, p. 5.

PRACTICAL APPLICATIONS OF NORMAL PROBABILITY PAPER

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After listening to a particularly fine talk on a Quality Control technique, how often have we heard members of our section make these observations:

"Yes, it was a fine talk, and the speaker obviously knew his subject from A to Z. The theory he set forth is doubtless OK, but he didn't show us where it has been used as a practical day to day tool".

In other words, we are willing to accept theories provided by our long haired friends up in cloud 17, but how about giving us something practical that is being used, and which we can apply to our everyday operations.

It is with this idea in mind that this talk is being given to-day. You can be assured that anything you hear to-day will be practical because it is being given by a practical person who is engaged in applying statistical methods to the control of product quality in a manufacturing plant.

To-day some practical uses of normal probability paper will be presented. The development of probability paper, and the theory behind it, will be avoided to allow more time for practical applications.

This is not the only method of applying probability paper to the control of product quality. Other shorter, and perhaps better methods have been developed, but it is hoped by the end of this talk that you will see that this method does work for us. We also hope you will see where this technique can be applied towards the solution of problems in your own operations.

Now these questions may arise:

1. What is normal probability paper?

2. What is probability?

3. Where can I use probability paper?

4. What can the use of probability paper do for me?

5. How reliable are the results derived from the use of probability paper?

6. Is probability paper costly to use?

1. What is Normal Probability Paper?

Normal Probability Paper is graph paper with a normally spaced vertical scale for the measurements and a horizontal scale of cumulative percentages, so spaced that values plotted from a normal distribution will fall along or about a straight line.

ASQC LCS Code 552:70:439

2. What is Probability?

Probability is simply the likelihood or chance of occurrence. We can
say with a great deal of assurance that in all probability our Society
will continue to grow both in number and in its ability to serve indus-
try. This we can understand, because after all we have completed some
16 years of steady growth. However, can we say with the same assurance
that in all probability a manufacturing process will or will not pro-
duce parts within specified tolerance by examining a small sample of
the product at the start of a run. This is indeed a tall order, but
Normal Probability Paper is a Quality Control tool which will assist
you to do just that, as we will try to show in the practical demon-
stration.

3. Where can I use Normal Probability Paper?

In general, probability paper can be used wherever variables data can
be collected and recorded. The practical examples will, we are sure,
answer this question to your satisfaction.

4. What can the use of Normal Probability Paper do for me?

   A. Show if the parts measured come from a normal distribution.

   B. Determine $\overline{X}$ or average value.

   C. Determine standard deviation (σ) without extensive calculation.

   D. Make comparison with specification values.

   E. Predict percentages of production below or above any particular
       value.

   F. Assist in machine and process capability studies.

   G. Present information graphically.

   H. Provide a tool for trouble shooting.

   I. Indicate homogeneity of the product.

5. How Reliable is the Probability Paper Technique?

We will let the demonstration provide the answer to this question.

6. Is Probability Paper Costly to use?

Provided it is necessary to have the information obtained by the use
of Probability Paper, I know of no less expensive method. This will
also be shown in the demonstration.

Now let us consider where we can use Normal Probability Paper.

   A. To check the quality of incoming material and components.

   B. To check in process quality.

   C. To check machine or process capability.

Certain conditions must be met if we are to make successful applications
of Normal Probability Paper.

1. In the case of lot or batch inspection:

   A. Samples must be taken at random.

   B. The lot or batch must be homogeneous.

      (Probability paper will very quickly indicate a heterogeneous
      product.)

2. In the case of "in process" quality checks or machine capability checks:

   A. Measurements must be made on consecutive parts from the process.

   B. The set-up must not be changed in any way while the sample is
      being taken.

      (Should it become absolutely necessary to change the set-up, we
      must start sampling again when the new set-up has been satisfac-
      torily completed.)

3. In all cases:

   A. The measurements must be made accurately.

   B. The measurements must be taken by one and the same person using
      the same measuring equipment throughout the entire sample to
      avoid introducing a known assignable cause of variation into the
      study.

Now let us get on with the practical applications. -- In the first place
we will go through the mechanics of recording, calculating, plotting and
analyzing data. In this way it is felt that you will get a much better
grasp of the technique than you would if it was just explained to you.

....

                    "DEMONSTRATION"

....

That concludes the demonstration of the probability paper technique as we
apply it at Ward Street Works, Canadian General Electric Co. Ltd.

   We trust we have demonstrated successfully that this technique will do
all that we claimed it would do at the beginning of this talk. The more we
use this technique, the more it amazes us by its accuracy, reliability and
economy. Doubtless, you have some questions you would like to ask, and I
will do my best to give you the answers or get the answers for you if I
cannot give them personally.

QUALITY CONTROL	CANADIAN GENERAL ELECTRIC CO. LTD.			WARD STREET PLANT			
Part No. or Material Size	Name of Part or Type of Material			Dimension Checked		Vendor or Department	
44828 Pt.2	Binder Head Screw			Head Diameter .307" to .327"		All Nu Screw Co.	
SAMPLE NO.	SAMPLE SIZE 25			CHECKED BY: "C"		DATE: Jan. 7/58	
	X_1	X_2	f	cf	% cf	MidPoint %	Remarks
1	.314						
2	.316						
3	.316						
4	.313						
5	.320						
6	.315						
7	.315						
8	.316						
9	.315						
10	.314						
11	.315						
12	.314	.320	1	1	4	2	
13	.319	.319	1	2	8	6	
14	.313	.317	1	3	12	10	
15	.316	.316	6	9	36	24	
16	.314	.315	7	16	64	50	
17	.315	.314	5	21	84	74	
18	.314	.313	2	23	92	88	
19	.315	.312	1	24	96	94	
20	.315	.311	1	25	100	98	
21	.311						
22	.312						
23	.316						
24	.316						
25	.317						

QUALITY CONTROL	CANADIAN GENERAL ELECTRIC CO. LTD.		WARD STREET PLANT
Part No. or Material Size	Name of Part or Type of Material	Dimension Checked	Vendor or Department
44828 Pt.2	Binder Head Screw	Head Diameter .307" to .327"	All Nu Screw Co.
SAMPLE NO.	SAMPLE SIZE 25	CHECKED BY: "C"	DATE: Jan. 7/58

SAMPLE NO.	X	$X - \bar{X}$	$(X - \bar{X})^2$	CALCULATION FOR $\bar{X}$ AND σ
1	.314	− 1	1	
2	.316	+ 1	1	$\bar{X} = \dfrac{\Sigma X}{N}$
3	.316	+ 1	1	$= \dfrac{7.886}{25}$
4	.313	− 2	4	$= .315$
5	.320	+ 5	25	
6	.315	0	0	
7	.315	0	0	
8	.316	+ 1	1	
9	.315	0	0	$\sigma = \sqrt{\dfrac{\Sigma(X - \bar{X})^2}{N - 1}}$
10	.314	− 1	1	$= \sqrt{\dfrac{89}{24}}$
11	.315	0	0	$= \sqrt{3.7}$
12	.314	− 1	1	$= 1.9 = .0019"$
13	.319	+ 4	16	
14	.313	− 2	4	$+ 3\sigma = .315" + .0057" = .3207$
15	.316	+ 1	1	$- 3\sigma = .315" - .0057" = .3093$
16	.314	− 1	1	
17	.315	0	0	
18	.314	− 1	1	
19	.315	0	0	
20	.315	0	0	
21	.311	− 4	16	
22	.312	− 3	9	
23	.316	+ 1	1	
24	.316	+ 1	1	
25	.317	+ 2	4	
	ΣX 7.886		$\Sigma(X-\bar{X})^2$ 89	

CHOOSING A SEQUENTIAL TEST[*]

N. L. Johnson
Case Institute of Technology

1.   The basic philosophy of 'sequential analysis' is now becoming fairly well established among both theoretical and experimental statisticians.   The latter are becoming accustomed to include sequential methods among the possible ways of attacking their problems; the former are producing an increasingly varied set of available techniques.

By 'sequential methods' we mean methods of statistical enquiry which do not have a rigidly pre-determined pattern (as, for example, the classical 'experimental designs') but which contain provisions for re-orienting, or concluding, the investigation according to rules operated by the data as they are collected. It can readily be appreciated that by this means it should be possible to avoid the waste involved in completing a pre-determined program when it is reasonably clear, at a relatively early stage, what the final conclusions will be.

In the technical application of sequential methods there are as yet a number of points which are of some importance but do not always receive the attention they deserve. They arise, mainly, from the fact that the expected behavior of a sequential procedure depends on the real physical situation, not only in regard to decisions reached, as do fixed size sample procedures, but also in regard to length and pattern of investigation.

It is the purpose of this paper to draw attention to some of these points and to indicate simple _ad hoc_ methods by which they may, to some extent, be allowed for.

2.   The main impetus behind the development of sequential techniques has been the existence of the Sequential Probability Ratio Test (s.p.r.t.) procedures derived from the fundamental work of Wald [1]. In the original form of such procedures, two simple hypotheses (H_o and H_1, say) are compared by the following rule, using the likelihood ratio $\ell_n = p_{1n}/p_{0n}$ (of H_1 to H_o) calculated from a random sample of size n:-

"Accept H_o if $\ell_n \leq \alpha_1/(1-\alpha_o)$.

" H_1 if $\ell_n \geq (1-\alpha_1)/\alpha_o$.

Otherwise take a further observation".

For such a procedure we have

(1) $\Pr\{\text{Accept } H_{1-i}|H_i\} \doteqdot \alpha_i$ (i = 0,1) .

α_o and α_1 are always less than 1 and usually rather small; conventional values are usually in the range 0.005 to 0.05. The average size of sample (a.s.n.) is approximately

(2) $k_o\left[\alpha_o \log \dfrac{1-\alpha_1}{\alpha_o} + (1-\alpha_o) \log \dfrac{\alpha_1}{1-\alpha_o}\right]$ when H_o is true.

(3) $k_1\left[(1-\alpha_1) \log \dfrac{1-\alpha_1}{\alpha_o} + \alpha_1 \log \dfrac{\alpha_1}{1-\alpha_o}\right]$ when H_1 is true

where $k_i = [\mathcal{E} (\log \ell_1|H_i)]^{-1}$.   (i = 0, 1)

An important property of the s.p.r.t., and one of its most convincing reasons for adoption, is that no other procedure satisfying (1) can have smaller a.s.n.'s than (2) or (3), <u>when</u> H_o, H_1 <u>respectively are true</u>.

3.   Suppose that it has been decided to use a s.p.r.t. We must then, in order to define the rules of procedure, choose H_o, H_1 and also α_o, α_1. It is a remarkable fact that in many cases (judging from both published accounts and informal conversations) the choice of H_o and H_1 is not primarily based on consideration of situations in which it is particularly important to reduce a.s.n. Perhaps as a legacy from earlier experiences of trying to obtain definitive statements of hypotheses to be tested and of required significance level and power, there is a marked tendency to define H_o and H_1 in terms of some physically threshold factor. Thus H_o may correspond to a (more or less arbitrary) specification value, and H_1 to some (also arbitrary) limit of 'undesirable quality'. It may very well be quite reasonable to require certain values of power (or OC) for these two situations, but, also, a.s.n. minimisation may well be more desirable in some other situation (H say) either because

(a)   H occurs much more often than H_o or H_1,

or   (b)   experimentation is more costly when H is true (e.g. if H corresponds
            to dangerously low efficacy of a drug).

Or, of course, combinations of factors of these kinds.

4.   With sufficiently detailed prior information <u>and</u> sufficiently powerful computing resources it would be possible to attain a completely satisfactory solution. Suppose, for example, that the physical situation is defined by a parameter θ, that θ has a known prior distribution $g(\theta)$, that the average cost of sampling when a procedure S is used in situation θ is $C(\theta,S)$ <u>and</u> that the average loss (due to non-optimum decisions) is $L(\theta,S)$, then the average total cost (of sample and decision) using procedure S, could be represented as

$$K(S) = \int g(\theta) \cdot [L(\theta,S) + C(\theta,S)] \, d\theta.$$

Then the problem is to choose S to minimise $K(S)$. Quite possibly very difficult, but it is a direct explicit problem. Unfortunately, the postulated wealth of information about $g(\theta)$ and $L(\theta,S)$, and sometimes even about $C(\theta,S)$, is not often available.

However, there is frequently enough information available to make possible a more rational selection of sequential procedure than a purely á prioristic choice of H_o, H_1 combined with a conventional choice of α_o, α_1. In the following sections some ways in which additional information can be utilized in the construction of a procedure will be described. These methods are necessarily variegated, since prior information can exist in widely varying amount and nature.

5.   Firstly we consider a very simple case. Suppose that H_o and H_1 represent the <u>only possible</u> sets of physical conditions. Suppose further that the prior probability of H_o is ω_o, and of H_1, ω_1, with $\omega_o + \omega_1 = 1$. (This corresponds to the $g(\theta)$ of section 4.) Suppose that we wish to make the (approximate) overall probability of an erroneous decision equal to α, i.e.

(4) $\omega_o \alpha_o + \omega_1 \alpha_1 = \alpha$.

Then, from (2) and (3), the overall a.s.n. is approximately

(5) $\omega_o k_o \left[\alpha_o \log \dfrac{1-\alpha_1}{\alpha_o} + (1-\alpha_o) \log \dfrac{\alpha_1}{1-\alpha_o} \right] + \omega_1 k_1 \left[(1-\alpha_1) \log \dfrac{1-\alpha_1}{\alpha_o} + \alpha_1 \log \dfrac{\alpha_1}{1-\alpha_o} \right].$

In this very simple situation, with no specific costs to be considered, we can enunciate the problem as that of choosing α_0, α_1 to minimize (5), subject to (4). The solution is, in fact, that α_0, α_1 should satisfy the equation

$$(6) \qquad (k_0 + k_1)\log \frac{(1-\alpha_0)(1-\alpha_1)}{\alpha_0 \alpha_1} = \frac{1-\alpha_0-\alpha_1}{\omega_0\omega_1}\left[\frac{\omega_0^2 k_0}{\alpha_1(1-\alpha_1)} + \frac{\omega_1^2 k_1}{\alpha_0(1-\alpha_0)}\right]$$

as well as (4).

If $k_1 = -k_0$, as is the case, for example, when two possible values of the mean of a normal population are being compared, (6) becomes $\omega_0^2 \alpha_0(1-\alpha_0) = \omega_1^2 \alpha_1(1-\alpha_1)$ which on combination with (4) yields

$$\alpha_0 = \frac{\alpha(\omega_1 - \alpha)}{(1-2\alpha)\omega_0} \quad ; \qquad \alpha_1 = \frac{\alpha(\omega_0 - \alpha)}{(1-2\alpha)\omega_1} \quad .$$

It is evidently desirable to have $\alpha < 1/2$, $\alpha < \omega_0$, $\alpha < \omega_1$.

Costs can be introduced by supposing, for example, that the cost of an incorrect decision is c_0, c_1 when H_0, H_1 is true, respectively, and that the cost of sampling is c per unit, whichever hypothesis is true. α_0 and α_1 can then be chosen to minimize

$$\omega_0 c_0 \alpha_0 + \omega_1 c_1 \alpha_1 + c \times (5) \quad .$$

6. In the previous section we have seen how prior knowledge can be used to select appropriate error probabilities α_0, α_1. Now we will consider a case in which it has been decided to fix α_0, α_1 for values θ_0, θ_1 ($> \theta_0$) of a parameter θ, but not necessarily to minimize the a.s.n. at these values of θ. On the other hand, minimization of a.s.n. is desired at a value $\theta = \theta' < \theta_0$.

Out of a number of possible approaches we select for study those in which we restrict ourselves to s.p.r.t.'s discriminating between the hypotheses $H:\theta = \theta_0$ and $H_1':\theta = \theta_1'$ with error probabilities α_0, α_1' respectively, where θ_1' and α_1' are so related that $\Pr\{\text{Accept } \theta = \theta_0|\theta_1\}$ remains (approximately) constant at the pre-assigned value α_1. Then the question to be answered is:- what value of θ_1' minimizes the a.s.n. when $\theta = \theta'$?

Since $\theta' < \theta_0$, and α_0 will presumably be small, $\Pr\{\text{Accept } \theta = \theta_0|\theta'\} < \alpha_0$ will be even smaller and the a.s.n. when $\theta = \theta'$ is approximately

$$(7) \qquad k' \log [\alpha_1'/(1-\alpha_0)]$$

where $k' = [\,\mathcal{E}(\log f_1|\theta')]^{-1}$, f_1' being the likelihood ratio of $\theta = \theta_1'$ to $\theta = \theta_0$ for a single observation. α_1' and θ_1 are linked by the equation

$$(8) \qquad \frac{1 - [\alpha_1'/(1-\alpha_0)]^{h'}}{[(1-\alpha_1')/\alpha_0]^{h'} - [\alpha_1'/(1-\alpha_0)]^{h'}} = 1 - \alpha_1 \quad \text{where } h' \text{ satisfies}$$

$$\mathcal{E}\left(f_1'^{h'} \mid \theta_1\right) = 1 \quad .$$

If $\theta_1' < \theta_1$, h' is less than -1 and (8) yields

$$\log\left(\frac{\alpha_1'}{1-\alpha_0}\right) \doteq -h'^{-1} \log \alpha_1$$

so that (7) is approximately equal to

$$(-k'/h') \log \alpha_1$$

Again taking the case where θ represents the mean of a normal population we find

$$h' = (\theta_0 + \theta_1' - 2\theta_1)/(\theta_1' - \theta_0)$$

$$k' \subset - (\theta_0 + \theta_1' - 2\theta')^{-1} (\theta_1' - \theta_0)^{-1}$$

so that the a.s.n. at $\theta = \theta'$ is approximately proportional to

$$- [(\theta_0 + \theta_1' - 2\theta_1)(\theta_0 + \theta_1' - 2\theta')]^{-1}$$

$$= - [(\tfrac{1}{2}(\theta_0 + \theta_1')-\theta_1)(\tfrac{1}{2}(\theta_0 + \theta_1')-\theta')^{-1} \quad .$$

So, within the accuracy of this approximation the a.s.n. at $\theta = \theta'$ is minimized when

$$\tfrac{1}{2}(\theta_0 + \theta_1') = \tfrac{1}{2}(\theta' + \theta_1)$$

i.e. $\theta_1' = \theta_1 - (\theta_0 - \theta')$.

The ratio

$$\frac{\text{a.s.n. using s.p.r.t. with } \theta_1' = \theta_1 - (\theta_0-\theta')}{\text{"   "   "   " } \theta_1' = \theta_1}$$

is approximately $\dfrac{\theta_1 - \theta_0}{\theta_1 - \theta'} \left[2 - \left(\dfrac{\theta_1 - \theta_0}{\theta_1 - \theta'}\right)\right]$.

7. If we are interested in reducing a.s.n. for values of θ __between__ θ_0 and θ_1 other techniques, of recent development, are available. This problem has received special attention, perhaps because it is in this region that the a.s.n. of the s.p.r.t. reaches a maximum. It is known, for example, that in the normal case discussed in the previous sections, the s.p.r.t. with $\alpha_0 = \alpha_1 < 0.008$ has a greater a.s.n. when $(1/2)(\theta_0 + \theta_1)$ than the size of the fixed size sample needed to discriminate between the hypotheses $\theta = \theta_0$, $\theta = \theta_1$ with the same power.

The techniques developed to deal with this type of problem actually change the form of test from the standard s.p.r.t. procedure. Anderson[2] has described a promising procedure which is essentially based on the comparison of $/n$ with certain linear functions of n in place of constants, as in the s.p.r.t. By trial and error he was able to obtain a test with a.s.n. at $\theta = (1/2)(\theta_0 + \theta_1)$ not much in excess of a lower bound for the a.s.n. of any test with given discriminating power (between

$\theta = \theta_o$ and $\theta = \theta_1$) obtained by Hoeffding[3]. The table below, based on information in [2] and [3] illustrates the properties of Andersons's test.

$\alpha_o = \alpha_1$	$\theta =$	Fixed size sample	s.p.r.t.	a.s.n. for Anderson's test	Lower bound
0.01	$\frac{1}{2}(\theta_o + \theta_1)$	541.2	527.9	402.2	388.3
	θ_o or θ_1	541.2	225.2	249.4	225.2
0.05	$\frac{1}{2}(\theta_o + \theta_1)$	270.6	216.7	192.2	187.0
	θ_o or θ_1	270.6	132.5	139.2	132.5

Professor W. J. Hall, of the University of North Carolina, has kindly informed me of a method which promises to provide useful test procedures while avoiding the necessity for such heavy calculations as we entailed in constructing optimum procedures by Anderson's method. He proposes to replace the standard s.p.r.t. based on $\lambda_n = p_{1n}/p_{0n}$ by two standard s.p.r.t.'s, one discriminating between $\theta = \theta_o$ and $\theta = \theta'$, the other between $\theta = \theta'$ and $\theta = \theta_1$ (where θ' is the value of θ at which minimization of a.s.n. is desired, and $\theta_o < \theta' < \theta_1$). The procedure terminates when $\theta = \theta_o$ is accepted by the first test, or $\theta = \theta_1$ by the second test, but not when $\theta = \theta_o$ is accepted by either test. It seems reasonable to take error probabilities α_o, α_1 when $\theta = \theta_o$, $\theta = \theta_1$ respectively, and, perhaps, to base the error probabilities when $\theta = \theta'$ on the value of the OC at $\theta = \theta'$ for the standard s.p.r.t. discriminating between $\theta = \theta_o$, $\theta = \theta_1$ with error probabilities α_o, α_1 respectively. The selection of error probabilities does not yet seem to be well-established. But this does seem a practically useful way of constructing a test procedure appropriate to the conditions described. In the normal case it gives a procedure of the same form as Anderson's. It is, of course, quite a general method, not limited to the normal case.

8.   This paper cannot be more than a rather superficial survey, because it describes a relatively unexplored field with many possible, and practically important, variations in detail. But the cases described should suffice to show that variation on standard s.p.r.t. techniques, to meet special requirements, need not call for very deep or heavy mathematical work, while it should also be clear that it is important, even essential, to allow for these special requirements. There should be constant care not to become hypnotized by the two hypotheses and two error probabilities which play a central role in formal sequential analysis.

Some problems of the kind described in section 6 have been treated in a more detailed manner in an earlier paper by myself[4]. The present paper is, however, much broader in scope than [4], which also contains some numerical tables of use in constructing sequential procedures.

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[2] Anderson, T. W. "A modification of the sequential probability ratio test to reduce the sample size", Ann. Math. Statist., Vol. 31 (1960), pp. 165-97.

[3] Hoeffding, W. "Lower bounds for the expected sample size and the average risk of a sequential procedure", Ann. Math. Statist., Vol. 31 (1960), pp. 352-68.

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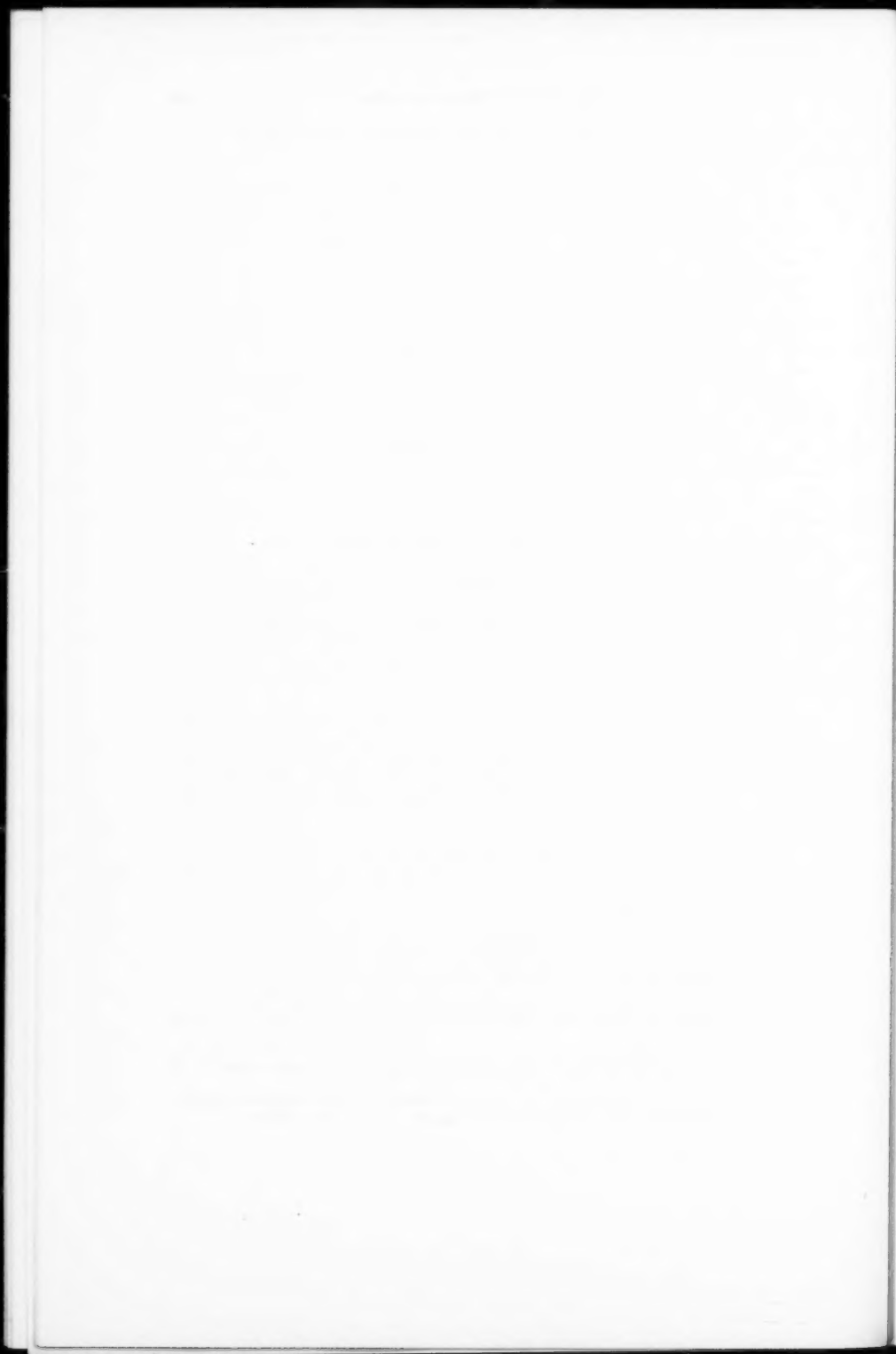
TEST PERFORMANCE CHARTS

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A common method used for analyzing test results of complex units is to graph unit performance based on review of the test data. This can be done in two ways -- analysis of individual test measurements, or monitoring quality levels on an attribute basis.

Any one test may involve a considerable number of test steps, each of which might be subject to detailed analysis. Regardless of benefits obtained in monitoring individual test measurements on the floor with testers plotting $\overline{X}$ and R-chart data, complex unit testing may involve dozens of charts for any one test position. To keep the program in operation, this would present a major problem in the piling up of paperwork. Hence, the "go, no-go" approach permits quality level floor controls without time-consuming clerical work.

The authors have devised a method whereby the individual tester can monitor quality levels without waiting for performance interpretation at a later time. This is handled on a single "Test Performance Chart" (see Fig. 1).

These test performance charts are a modification of those copywrited in 1955 by Emerson Research Laboratories. They are posted on each test position where they are clearly visible and easily plotted. The results of each test are noted immediately after the complete test cycle.

This chart is made up of a series of grids, as illustrated in Fig. 1. Testers plot only initial tests, which gives the true manufacturing quality level at all times. If the unit is completely acceptable, the tester marks an "X" on the diagonal "right-upwards". If a unit fails for any reason, the tester indicates a "right-downwards" plot on the diagonal. To provide supervision with information concerning differences between testers on the same position, or differences for two-shift operation, different symbols may be used to indicate unit acceptance or suspension.

Each chart is originally entered adjacent to the chart apex with an appropriate plot indicating test acceptance or suspension. Subsequent plots are entered until the entire plotting area is used up. The chart is basically designed for 100 tests.

The slanting guide lines indicate acceptance levels in terms of accumulative acceptance rates. As soon as the tester plots the most recently completed test result, he has before him, and to anyone else within the area, the exact accumulative test acceptance rate for the indicated number of units tested. Where several test positions are used to test the same unit, these test performance charts are very effective in determining if acceptance rates are compatible among the test positions. Similarly, these charts readily show which units of various types are going to require additional engineering effort to improve the performance of any one unit.

At the completion of each test performance chart, the tester obtains a new chart, fills in all printed headings, and again enters test results beginning adjacent to the chart apex. After two such charts are completed, they are analyzed to determine what the authors choose to call a "control cone." These control cones, essentially 2-sigma control limits for "p" charts, are marked as indicated in Fig. 1. At the completion of the third and subsequent charts, if the last plot on each sheet falls below this control cone, the tester notifies his immediate supervisors promptly, and investigation is made to determine the cause of this falling off in process quality. It is, of course, just as important to find out why the process improved if the last plot per sheet falls above the control cone. As supplementary information, testers also indicate on the chart information concerning product acceptance changes, such as test position calibration, engineering changes, new manufacturing lot initiation, test position modification, etc. Subscripts are noted on the chart to indicate such changes, with brief remarks entered near the chart apex.

The test performance charts are also used to determine the effectiveness of an engineering change. For example, subscript #3 as shown in Fig. 1 indicates the incorporation of an engineering change. It is evident that product quality quickly improved. It is possible to calculate how many units are required to detect such an

improvement and how many suspended items are allowed for this improvement in product quality.

Further statistical information is furnished to the tester, designated as a "failure run limit" and a "failure rate." The failure run limit is provided to permit the tester to know exactly when successive failures are indicating a significant deterioration of test quality.

Let us assume that we have a test position which has shown an average acceptance rate of 80 percent over 200 tests (2 sheets). The failure rate is thus 20 percent. This 20 percent failure rate is the same as 1:5. Therefore, the probability of finding a significant deterioration in test quality may be determined. At the observed failure rate of 1:5, the probability of testing two discrepant units successively would be:

$$(1/5) \ (1/5) = \frac{1}{25}$$

Obtaining three discrepant units successively would be:

$$(1/5) \ (1/5) = \frac{1}{125}$$

The odds for noting three discrepant units are seen to be very small (1:125). The authors consider odds of 1:100 as significant for this type of operation. Consequently with the example given, the failure run limit would be given as three (3). The failure rate would be given as 1:5.

This failure rate can be used to substantiate product quality deterioration. If the failure run limit is reached but there is no apparent cause or pattern of test failure, an additional number of tests may be made as prescribed by the failure rate to try to detect the cause. For the above example, five more tests could be run. If only one failure was observed, testing would be permitted to continue.

This concept of seemingly giving more leeway in terms of "take another look" is a conciliation between setting down hard and fast statistical ground rules and the problems of maintaining schedule and supervision's cooperation.

Once the control information is provided, regular reviews of subsequent sheets are maintained by the quality engineer with a view toward upgrading control cones and appropriate changes in failure run limits and rates if significant product quality improvement is noted.

SUMMARY

The test performance charts require a minimum amount of the testers' time to maintain. These charts are always up to the minute, indicating the present quality level of the product going through a test position. The testers, through channels, are able to inform quality and engineering personnel when the failure run limit has been reached for a particular test position so that prompt action can be taken to prevent excessive failures. On the completion of each sheet, the tester is also able to inform cognizant personnel when there has been a significant change in the process average. No clerical or analytical work is required from the testers to maintain these charts.

For purposes of maintaining long range quality histories of a process, a "p" chart (not shown in Fig. 1) is attached to the lower left-hand corner of the test performance chart holding fixture. On this "p" chart, the accumulative test acceptance rate is plotted at the completion of each sheet. Control limits are provided to indicate the normal expected variability.

The success of this program was based upon the following:

(1) Simplicity of operation
(2) The desire of quality and engineering personnel to be part of this program.
(3) The placing of direct responsibility upon the tester to initiate corrective action for "on-the-spot" feedback of information to responsible departments.

Some of the results obtained in this program are:

(1) Improvement of product reliability
(2) Reducing rework and scrap
(3) Promote operator and/or inspector interest on the job
(4) A guide for production supervision
(5) An effective tool for engineering.

References:

(1) Morten Gale "Plotting of Success or Failure Test Results"
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FIGURE 1
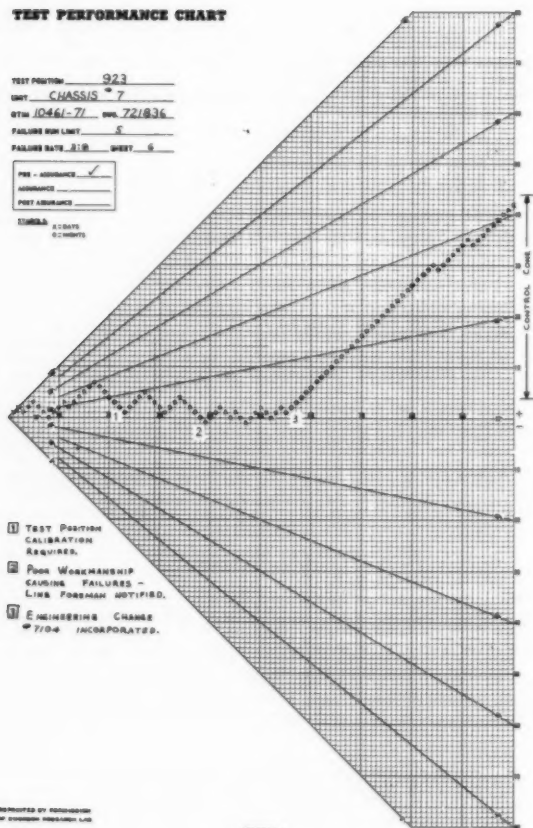
INDUSTRIAL APPLICATIONS OF NONPARAMETRIC STATISTICS

Edwin C. Harrington, Jr.

MONSANTO CHEMICAL COMPANY

Very often, in industrial and in scientific investigations, we are faced with the problem of analyzing and interpreting data obtained from an arbitrary and subjective scale of measurement. The appearance of a painted object after exposure to the weather might be rated as poor, fair, good, or excellent. Or we might have several batches of one product, of which one can only say that batch A is better than B, B is better than C, etc. In situations of this sort, although we can attach numbers to the several classes, the numbers indicate order, only - i.e., an ordinal scale - and the usual properties of numbers - addition, subtraction, multiplication, and division - are no longer valid operations. For example, batch D, ranked as No. 5, is not necessarily three "units" worse than batch B, ranked as No. 2.

For this reason, the common methods of analysis based on an interval or ratio scale of measurement, do not apply. Many of the well-known statistical methods, "t" tests, the analysis of variance, even $\bar{X}$ and R control charts, depend upon the numerical properties of an interval scale, i.e., a scale in which the interval between ranks has meaning. Another restriction to the use of the common analytical procedures is their assumption an approximately normal (Gaussian) distribution of the observations on this scale. To meet these difficulties, the so-called distribution-free nonparametric procedures have been developed.

Consider the problem of comparing two paints for weather resistance. Ten panels might be prepared from paint A and ten from paint B. All twenty are exposed to the weather for a year and then compared for overall appearance. Quite a number of measurements might be made: total exposed area, number of pinholes, total blistered area, length of checks and cracks - all of questionable reliability and probably none of greater practical value than a simple ordering of the twenty panels from best to worse.

If the A's are all better than the B's, or vice versa, there is hardly any question of interpretation. The recording from good to bad would be:

AAAAAAAAAABBBBBBBBBB

and the conclusion obvious.

The other extreme situation would result if the two paints were really the same. Here we would not be favored with a nice symmetrical pattern, such as

ABABABAB..........

but rather, with a random distribution of A's and B's, such as:

ABABBBAABAABABBBAABA

If the expected pattern were symmetrical ABABAB, it would be easy to detect even the smallest difference between A and B. Since the expected pattern is actually random, it becomes more difficult to decide that a difference does exist - and also, a larger difference must exist between A and B if one is to detect it.

Suppose in a test of the two paints, A and B, the ordering from good to bad were as follows:

> AABAAABABABAABBBABBB

The A's trend toward the good end and the B's toward the poor end, and yet it does not seem too unlikely that this distribution could arise by chance (consider the tossing of a coin). The statistical problem is to calculate the probability that this distribution could actually arise by chance. If the distribution could reasonably be accounted for by chance, there is not sufficient evidence to say that the two paints are different. On the other hand, if it is relatively unlikely that this is a pure chance distribution (say it would occur by chance less than 5% of the time), then we can reasonably say that B is poorer than A.

The Mann-Whitney U Test.

The non-parametric procedures, of which there are now very many, are designed to calculate these probabilities. One of the most useful and most efficient of the nonparametrical procedures is the Mann-Whitney U Test, provided the conditions for its application are met. This test applies where two independent groups are compared, and where they are arranged in an ordinal scale, such as from large to small, from good to bad, from smooth to rough, etc. The Mann-Whitney U Test is appropriate in this paint film example.

The procedure is to calculate the statistic U, and it is done in this manner:

1. Arrange the observations in a single ordered series, from best to poorest, from most to least, or by whatever criterion is appropriate.

2. Of the two independent groups, identify one as the n_1 group (usually the smaller), and the other as the n_2 group.

3. Starting at either end of the ordered series, count the number of times a member of n_2 precedes each member of n_1. The sum of these counts is U, or its compliment, U'. (U' is what you would get if you started to count from the wrong end. It is related to U by the equation:

$$U = n_1 n_2 - U'$$

Intuitively, it is not difficult to see how U varies with the type of ordering within any series. If all of the A's precede all of the B's, U is obviously zero. As the A's and B's become more intermingled, the value of U will increase from zero to some maximum value, approximating $n_1 n_2 / 2$, which will occur when the A's and B's are alternate. From the point of view of hoping to distinguish between the two groups, we would normally hope for a small value of U. As U increases, there is a critical value, beyond which it must be concluded that the distribution of A's and B's is due to chance, and these critical values are published (1) for various values of n_1 and n_2. For ten observations in each group, the critical value (Pr=0.05, two tailed) is 23.

For the ordered series of the paint exposure test, there are ten panels in each group, so we may arbitrarily select the A's as the n_1 group. For the first A, there is no preceding B, and the count is zero. Similarly, the next count is zero. However for the third, fourth, and fifth A, the count is one for each A. This counting process is continued for all A's, and the total U score is

$$U = 0+0+1+1+1+2+3+4+4+7=23$$

Since the calculated U is just at the critical value, this means that there is only a 5% probability that the pattern of A's and B's could result from chance of two identical paints, and so it is concluded with 95% confidence that A is really superior to B.

Because the panels were not graded against a standard scale, it is not possible to express their merit except in relation to each other. This relation is correctly expressed in terms of the median (averaging is not allowable on an ordinal scale), and the median rank of A is 7.0, and that of B, 14.5.

The non-parametric procedures are useful not only in situations where their use is required, but also as optional procedures where the standard parametric methods would ordinarily be used. In this application there is usually a considerable saving in time with some, but often negligible, loss of efficiency.

Had we measured the surface gloss of the paint panels with a suitable gloss meter, data would be available for analysis by means of the parametric "t" test. This would require a moderate amount of calculation, and would require that the observations be normally distributed. The Mann Whitney Test could be completed by inspection, and it requires no assumption of normality.

The Binomial and Sign Tests.

At the present, there are many non-parametric methods available, of which the Mann Whitney Test is typical. Some of these have immediate and useful application in the interpretation of control charts, as, for example, the Binomial Test of which the well-known Rule of 7 is a special case. If observations are equally likely to fall into one of two classes, as the points of a control chart are equally likely to fall above or below the median, then the probability of a pattern such as 10 above and 3 below is readily calculated by the binomial distribution. The question a production man would ask is, does this pattern of 10 above and 3 below indicate a change of level? Should corrective action be taken? Calculation, or reference to a table, will show that such a pattern will occur about 9% at the time even when no change in level has occurred. And the recommendation would be to wait for more convincing evidence before changing process controls (thus avoiding overcontrol) unless defective material is actually being produced. The Binomial Test is quick and easy, requiring only the ability to count and the availability of a table (1).

The Sign Test is an extension of the Binomial, and it is useful in comparing two materials when they are tested in pairs. Consider the evaluation of two glues, X and Y. The major problem in evaluating glue is to get a uniform substrate, particularly if this is wood. It is accepted procedure to divide each test piece, and treat one half with X and the other with Y. Each half is then split, glued, and broken. Based on the appearance of the break (failure through the glue line or failure through the wood), X is rated superior to Y, or Y superior to X. Quantitative measures of the type of break, which are sometimes used, are of questionable value and are very often misleading.

In the sign test, a plus sign is used to indicate the superiority of
one sample of the pair, and a minus sign to indicate the superiority
of the other sample. Judgment of whether there is sufficient evidence
to conclude the overall superiority of one sample or the other is
based on the distribution of the plusses and minuses by comparison,
again, with tables of the binomial distribution. Thus, if 100 pairs
are tested, a split more divergent than 40:60 is sufficient evidence
to conclude with 95% confidence that one sample is superior to the
other.

In this example, not only is the sign test much easier to apply, it is
also preferred to a "t" test based on measures of percent "wood
failure" since the latter are far from normally distributed. The wood
failure distribution is markedly "U" shaped, and thus the assumption
of normality is not obtained.

A discussion of non-parametric statistics could well occupy a full
semester course, for the ingenuity of many statisticians has
developed an extensive field. Non-parametric Statistics, by S.Siegel
(McGraw-Hill) is an interesting and extremely valuable discussion of
the theory and methods currently available.

In summary

1. Where data are non-parametric to start with (scores,
   ranks, grades), the analysis should also be based on
   non-parametric procedures. Care should be taken to
   avoid a not uncommon practice of substituting numbers
   which are then treated as parametric.

2. Where data are parametric, (measured on at least an
   interval scale), it is occasionally true that the
   assumptions of parametric analysis are not obtained
   (in particular, the assumption of near-normality).
   In this case, a non-parametric procedure should be
   used in the analysis of the data.

3. When parametric analysis is appropriate, the simplicity
   of the non-parametric methods may still recommend their
   use. There is always some loss of efficiency, but this
   is important only in those borderline cases where a
   detailed study is then most certainly warranted.

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2. Some Rapid Approximate Statistical Procedures,
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March 9, 1961
Springfield, Massachusetts

dmh

KEEP IT ON THE SQUARE

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The life of a quality control man is pleasant, so long as all of the little dots stay cozily within The Control Limits. But when the dots start "headin' for the Border", the situation changes. What does the QC man do then? There are at least three possible courses of action.

a. Press the "out of control" button, and let Production clean up the mess. The QC'er who is content to spend his life separating the product into piles marked "Good" and "Bad" will take this course.

b. I'm sure this has been said better by somebody else sometime ago, but appropriate references have eluded me. If the Quality Control group has established the proper relationship with the Production Group, QC and Production will roll up their sleeves and, together, find out what's wrong and how to fix it.

c. If the situation is really idyllic, QC and Production would have studied the process together, some time ago, and would know which lever to pull or which valve to turn - and by how much - before such knowledge is needed.

Alternates (b) and, preferably, (c) require that the Quality Control people study the process as well as the product. Now I can cite references, sticking to IQC. Harold Kellogg (1) put it this way:

Statistical	With the help of numbers or data,
Quality	we can study the characteristics of any process in order
Control	to make it behave the way we want it to behave.

This importance of process study has long been recognized by the American Society for Quality Control, which, through the Chemical Division, sponsors courses, conferences and symposia on Response Surfaces and EVOP (2). That production experts and statisticians should work together is pointed out by Bicking (3). A subsequent article by Bicking (4) separates the process study group from the quality assessment group, but this can be afforded only by the larger companies. In general, a Quality Control engineer should be able and willing, to study processes as well as products. This paper discusses one simple little rule which will help us to plan our study so that we obtain more information with less work. That rule is - KEEP IT ON THE SQUARE.

To illustrate, let's look at something that's not on the square. Figure 1 is a photograph of a laboratory scale of common type. It has three feet, two of which are adjustable in height. On the base is a little spirit level of the bull's-eye type. To level this balance, you screw the two adjustable feet up or down, as needed. But it's not simple. You screw one foot up or down until the bubble is close to the bull's eye, then screw the other foot to home in. But changing the second foot throws off the adjustment made with the first foot, so you have to diddle back and forth. In mathematical language that's successive approximations. It's tedious.

Figure 2 shows what's wrong. This is a plan of this balance. As Foot A is screwed up or down, the base rotates on the axis BC. As Foot B is screwed up or down, the base rotates on the axis AC. But angle ACB is acute, so motion of the bubble toward BC, has a component toward AC, and vice versa.

Figure 3 is a photograph of an analytical balance. This type, or something more modern, is well-known to all of us. It, too, has two adjustable and one fixed leg, but levelling it is easy. Figure 4 shows why. Again, this is a plan view. P and Q are two spirit levels of the tubular instead of the bull's-eye type. This is a convenience, and helps in explanation, but it's not necessary. The vital point is that angle ACB is a right angle, or 90°. Now when Foot A is screwed up or down, the base rotates around axis BC, and the bubble in Level P moves back and forth, but the bubble in Q merely rolls around in the tube, for Q is perpendicular to AC and parallel to BC. Foot A can be adjusted until the bubble in P is centered. Then Foot B can be adjusted until the bubble in Q is centered - and the balance is level. The P bubble won't budge as the Q bubble is shifted, and vice versa. The secret of success is 90° - this set-up is On

the Square. This is the difference between a tedious, cut-and-try procedure and a
simple, direct and unequivocal technique.

There's nothing mysterious about this. Whenever you can get two forces - two
vectors - two variables - two factors to move at right angles to each other, their ef-
fects will be mutually independent. If Foot A is Temperature, and if Foot B is pres-
sure, and we keep these at right angles to each other, we can move Temperature up and
down and see what this does to the process, and we can move Pressure up and down, and
see what this does to the process, and each effect will be independent of the other.
We'll get two direct, dependable, unequivocal answers: The effect of Temperature, and
the effect of Pressure. If our experiment is not On the Square, we'll get an answer
which is partly due to Temperature, partly due to Pressure, and we'll never be sure
which is which.

What's this about Temperature being perpendicular to pressure? If you use a
dimensionless scale, this is more easily accomplished than explained.

If everything is perpendicular to everything else, the angles are all 90°, so the
angles are all equal. The Greeks, of course, had words for such situations - ortho is
equal, gonal is angle, and orthogonal is equi-angled. If one variable is orthogonal to
another, the vectors are perpendicular to each other. Keep the variables orthogonal,
and the experiment will be On the Square.

How do you recognize orthogonal variables when you meet them? The variance of
their cross-products will be Zero. Then everything is independent of everything else,
and the experiment is simple to run, simple to calculate, and definite in its answers.
You can "level-out" the process in a few simple stages.

Let's take a simple illustration. We want to find out what happens to tensile
strength when we (a) shift the temperature from 500° to 600°, (b) shift the reaction
time from 4 hours to 8 hours and (c) use 5% or 10% of Supposium Perhapsonate.

First, let's do some Orthogonal Coding. Three simple equations can be set up -

$$A = \frac{Temperature - 550°}{50°}$$

$$B = \frac{Time - 6\ hours}{2\ Hours}$$

$$C = \frac{\%\ SP - 7.5\%}{2.5\%}$$

This simple trick means that when we use a temperature of 500°, we simply say that
A is -50 over 50, or -1. When we use a temperature of 600°, A is +1. Similarly, B is
either -1 or +1, and C is either -1 or +1. That's sort of handy, isn't it?

Now we'll set up some experiments:

Run	Temp.	Time	S.P.	A	B	C
1	500	4	5	-1	-1	-1
2	600	4	5	+1	-1	-1
3	500	8	5	-1	+1	-1
4	500	4	10	-1	-1	+1

You'll recognize this as the ordinary approach - start with the standard state and
bump each variable at a time. What do we get out of this? Try the cross-product of A
and B - it adds to 0. But the sum of A is -2, and the sum of B is -2, and -2 times -2
over 4 is +1, so the variance of AB is 0 - (+1) or -1. It's not zero; we can't evalu-
ate A independently of B. AC and BC are in a similar fix.

How do we evaluate A independently of B and C? By using Runs 1 and 2 alone.

AB   0 - 0 = 0

AC   0 - 0 = 0

BC +2 - (+2) = 0

The same is true for B, using Runs 1 and 3, and for C, using Runs 1 and 4. All of this doesn't tell us anything new - anybody can see that moving A up and down while holding B and C constant will give you a measure of A independent of B and C. All I've done is to show that we get the same sensible answer from the orthogonal stand-point.

To get the most information for the least effort, we'd like to use all four runs to answer all three questions - what's the effect of A, or B, or of C? It's wasteful to use only Runs 1 and 2, Runs 1 and 3, and Runs 1 and 4. Only Run 1 is really being milked of its full value. How can we do better? By changing Run 1 from all low values to all high values.

Run	Temp.	Time	S.P.	A	B	C
1	600	8	10	+1	+1	+1
2	600	4	5	+1	-1	-1
3	500	8	5	-1	+1	-1
4	500	4	10	-1	-1	+1
				0	0	0

All these variables are orthogonal to each other - perpendicular to each other - independent of each other - On the Square. By the simple trick of switching from all low to all high, we make it possible to use all four runs for all three answers. By Keeping on the Square (or cube, in this case), we increased the power of our work 41.4% - yet we did no more work.

You recognize this design as a half-replicate of a 3-factor, 2 level factorial. All 2-level factorials are orthogonal. Setting up a 2^6 factorial is a simple, cookbook operation, but it also is an infallible method of drawing 63 lines all perpendicular to each other (in 63 dimensional space, of course). 3^n factorials are orthogonal for all quadratic terms. The Plackett and Burman designs are orthogonal. The Box-Wilson Center Composite, and the Box-Hunter Rotatable Designs are orthogonal. The DeBaun method of blocking these designs does not upset their orthogonality. Random Balance is not, was not, and never will be orthogonal. Two of many possible references to these designs are Cochran and Cox (5) and Chew (6).

Keeping on the Square adds power to our work. In the case of Analysis of Variance, however, orthogonality is more than a convenience; it is an absolute necessity. Every single term in an Analysis of Variance must be orthogonal to every other term, or the whole business is null and void.

Finally, I'd like to touch on Multiple Regression. Back on the old and not so good days when all we had was a hand-cranked calculator, we thought and planned before inverting a matrix. Now many of us take any old mess of data and pour it into the hungry maw of a Giant Brain and believe implicitly whatever spews out of the other end. It's all so quick and easy and untouched by human hand - or brain - that we have replaced our thought processes with a bunch of stupid electrons.

Here's what's going on. We say:

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \cdots\cdots b_i x_i$$

How many x's do we use? The tendency seems to be to drag in all we can think of, and then one more as an offering to the Unknown God. The Giant Brain doesn't know or care whether our choice of variables makes sense or not; for every "x" that we put in, the machine will give back a "b". And if we have 50 data points, put in any old 49 x's that we please, and the machine will give a perfect fit. Serves us right.

The next step in this foolishness is to run a t-test on each "b", to find the one that is least significant. This one is discarded, and the (n-1) x's are put back into the Brain. New answers are spewed out. Which set of answers is right? Neither, for another t-test says that we should discard another, and another, and another. Every time around, the surviving "b's" shift. When you finally stop this silly business, you report the "b's" as Gospel. But you know perfectly well that one more round would give a new set of answers. Aren't there any definite answers in this business? No -- unless the "x's" chosen are orthogonal to each other. And then you don't need a Giant Brain at all.

All of the data and the "x's" - fair or foul - are reduced first to Normal Equations. Then the normal matrix is inverted, and the "b's" come tumbling out. The Normal Equations look like this.

$$b_1 \, Sx_1^2 + b_2 Sx_1 x_2 + b_3 Sx_1 x_3 + b_4 Sx_1 x_4 + \text{------} = Sx_1 Y$$

$$b_1 \, Sx_1 x_2 + b_2 Sx_2^2 + b_3 Sx_2 x_3 + b_4 Sx_2 x_4 + \text{----} = Sx_2 Y$$

And so on and on. Most machine programs take the raw data, set up the Normal Equations solve these equations, and give you the answers without bothering you with these details. But, if you could see inside one of these monsters, you'd spot one Square term and (n-1) cross-product terms on each line. If your data are orthogonal, the cross-products all equal zero. There's nothing left in here but us squares. To get b_1, merely divide $Sx_1 Y$ by Sx_1^2, and so on - a desk calculator job.

What is more important is that, if b_{15} is practically zero, throw it out. Don't recalculate, for not another "b" has turned a hair. The x's are orthogonal - the variables are independent of each other - the equations are On the Square, and the answers are unique - definite - unaffected by the addition or dropping of other variables.

To be practical, we must recognize that there are many situations where all of our variables are not subject to our control. Sometimes the shift foreman influences the results, and people are notoriously non-orthogonal. Without air conditioning, we have to take humidity as it comes. However, it is still true that every variable that can be handled orthogonally should be handled orthogonally. A 30 x 30 matrix in which 28 factors are orthogonal and two are incorrigible can still be handled easily on a desk calculator, and the elimination of non-significant variables will have a small effect on the other regression coefficients. The square can be warped a little without losing all of its virtues.

To summarize: By using a little foresight in planning our work, we can choose a design which will arrange the variables orthogonally. This will:

1. Give us more information for less work.
2. Permit a valid Analysis of Variance.
3. Give definite answers with a minimum of calculating effort.

     KEEP IT ON THE SQUARE

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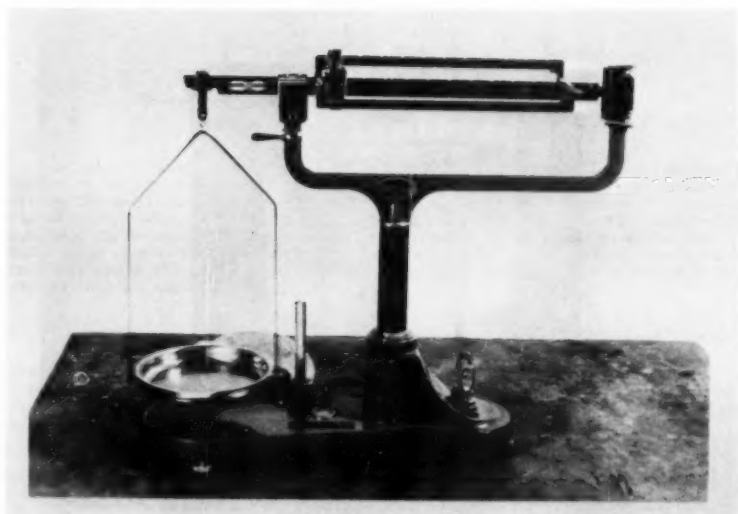
FIGURE I

ROUGH LAB SCALE
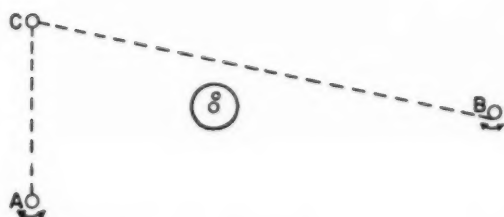
FIGURE 2
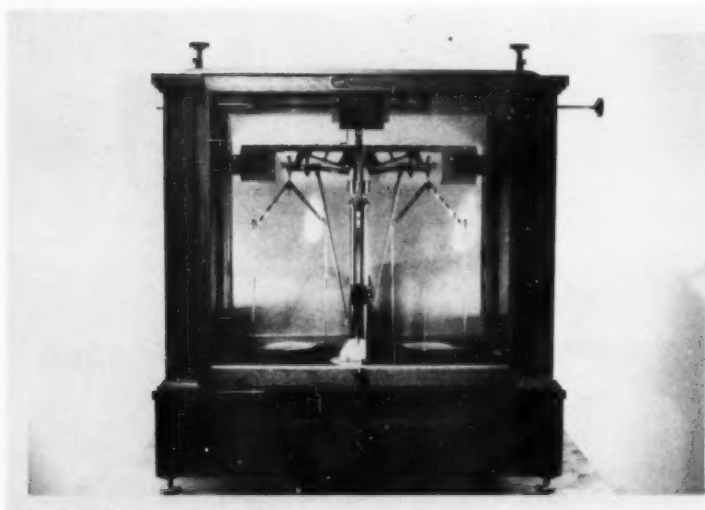
FIGURE 3

ANALYTICAL BALANCE

FIGURE 4

SHORT CUT STATISTICAL METHODS
as applied to certain
Reliability problems
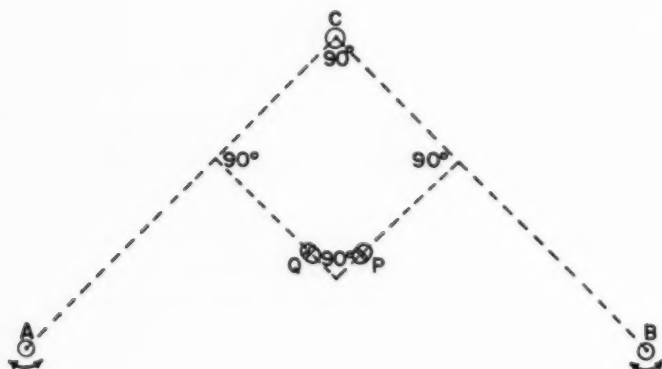
Gordon H. Beckhart
Radio Corporation of America

INTRODUCTION

As these methods may seem to by-pass a great deal of statistical theory generally applied to reliability problems, it would be best if first a little time was spent describing the particular problem confronting us. Our product line consists of a complex mix of heavy electronic equipment including many non-defense systems used for physics research. These equipments are generally needed before we have time to design and build them. Due to the time schedules and economics involved, selection methods must be streamlined. This paper describes some of the methods used and under what circumstances they are applicable.

RELIABILITY MATRIX

We believe that reliability may only be achieved by coordinated actions of all groups, from design to final emplacement of the equipment. In particular, Design, Production, and Field activities greatly influence the final reliability. In the design area, you will note, there are many activities that affect design reliability and a few are listed below as factors in the reliability matrix.

Each of these reliability factors is an engineering discipline requiring specialized professional knowledge and experience. Omission of any factor will eventually result in system shortcomings, while over emphasis on any one factor will increase the costs without necessarily improving system worth. Maximizing system worth per dollar expended is a managerial task requiring careful coordination and balance of the technical factors listed on the reliability matrix.

Part selection is one of these technical factors and judicious selection of parts will assist in the prevention of excessive assembly, repair and maintenance costs of the equipment.

LCS Code 810:60:400

WHAT IS RELIABILITY

Most published definitions of reliability make statements similar to "Reliability is the probability of performing without failure a specified function under given conditions for a specified period of time."[1]

This statement has been agreed upon by the best minds as being the most accurate and inclusive. Unfortunately, the psychological effect has been one of mass hypnosis within the electronics industry. The reason for the mass hypnosis is that the unsophisticated are lulled into a false sense of security that they know something about the reliability of parts if they have statistical data. Actually a part cannot be considered reliable until every failure mode is known, understood, measured, and controlled. If one has this knowledge, one may design around weaknesses with sufficient safety margin to prevent failures or to minimize the effect of the failure in the expected operating environment.
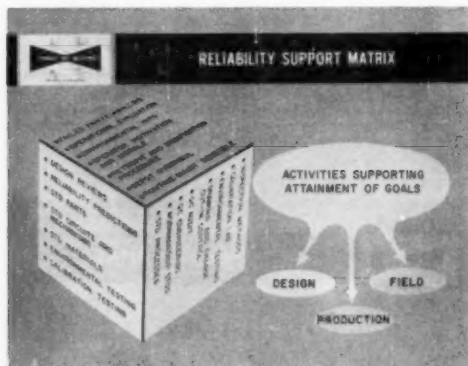
RELIABILITY SUPPORT MATRIX

While the do-it activities hold the option for ultimate equipment reliability they receive strong support from service activities. You will note that design reviews are included in the support matrix. The fact reviews are part of the support matrix does not imply that design reviews are organizationally separated from design but merely that this function is available within the organization to assist the designer. Several activities are listed on the support matrix to which statistically trained engineers are likely to be assigned. In these supporting activities the statistician is quickly introduced to all aspects of reliability enhancement.

TIME PHASING TYPICAL R & D PROGRAM

It is apparent from this schedule that if we have a contract calling for delivery of equipment two years hence, we will probably have a great difficulty meeting our schedule if a ten-thousand-hour life test is performed before parts are chosen for incorporation with the design. In fact, the life test for parts would probably use up most of the design and production time if we delayed the choice of parts until the conclusion of the life test. Let us assume for a moment that we have decided to run longevity tests on parts and examine a typical flow diagram of life testing activities.
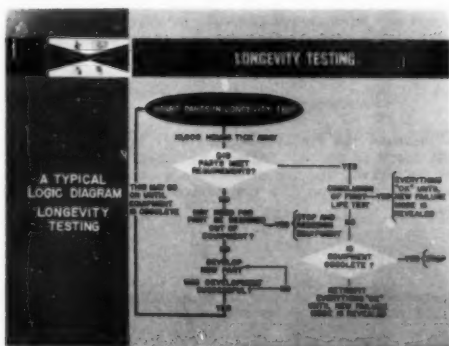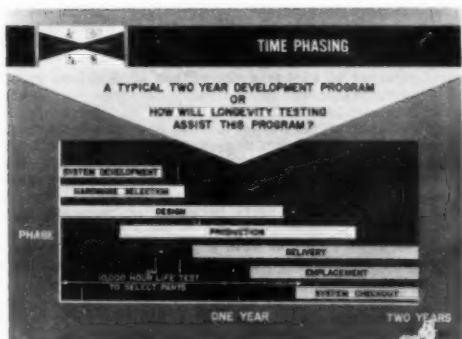
Looking at this diagram, one sees that if all goes well in the life test, there will be at least one cycle of ten-thousand hours. However, if the test is not success-ful, there may be many more ten-thousand hour cycles. In addition, by the time several life test cycles have been completed the equipment may be obsolete; a new part may have been developed which will be far more satisfactory from a performance point of view than the original part; or major circuit changes may have been added which elim-inate the need for the part. Therefore, on our ground equipment which is amenable to check-out and maintenance procedures the effects of part failure may often be avoided or side-stepped if it does not appear advisable to engage in considerable time, effort, and expense in longevity testing. Naturally those parts whose procurement will embrace several systems development cycles are subjected to longevity tests unless field in-formation is already available.

AN ALTERNATIVE PROCEDURE

This procedure is based on knowing, understanding, measuring and controlling failure modes. Therefore, we first study possible failure modes and choose the most rugged part or parts with respect to the mode of failure. Should weakness be revealed we try to increase the parts resistance to stress. Then our design checkout and maintenance procedures are adjusted to minimize the effect of failures upon the performance of the equipment.

Should we desire to determine part longevity we have the operating time of the equipment which will accumulate part-hours far faster than any life test stand. If you are not interested in determining mean-time between failure and keeping the necessary records but are interested in finding the best part, there are statistical techniques available for sampling the part distribution at intervals. One such system is based on starting with a 50-50 split of parts between suppliers.

Whenever a part fails it is replaced with a part made by the other vendor. Eventually the distribution of parts between vendors will indicate which part lasts the longest.

WHAT IS BEST ABOUT A PART RELIABILITY-WISE?

The answer to the question as to what is best about a part from a reliability point of view is a function of operational mission of the equipment, its environment and the maintainability of the equipment. In many applications, low failure rate is the most desirable property. However, the ability to withstand overload, a predictable wear-out period, or built-in indicators of malfunction may be even more desirable. Hence, to use a short-cut statistical method, one must first determine what attributes of a part are desirable and then conduct tests which will determine with a given risk that the best source or supplier of the parts has been selected. If we are selecting parts for equipment which may be designed for ease of maintenance, it appears that we should compare the gross stress withstanding ability of parts or the distribution of stress withstanding ability of parts. Our final choice should be that part most resistant to the various failure mechanisms.

STATISTICAL METHODS

This section will discuss six statistical methods; two of which are concerned with selecting the best based on percent defective, two of which are concerned with comparisons of percent defective, and two of which are concerned with the representativeness of samples and the selection of a population with the best median. The latter two use variables data.

Procedure I[2]

This procedure guarantees a probability P* of a correct decision regardless of the true configuration of the unknown parameter values (fraction effective).

To use this procedure in Table I you must:
1. Decide on the percent difference d* you wish to detect between the best and next best population.
2. Decide on the probability level P* that you wish to guarantee for selecting the best when the true difference between the best and next best is at least d*.
3. Look in the Table for the sample size "n" that must be tested from each population.

Example: We wish to be 80% sure of picking the best source when the best is at least 20% better than the next best. If we are comparing 4 sources, the required sample size is 23 items to be tested from each source. If we wish to be 99% sure of picking the best source in the same problem the required sample size is 89 items from each source.

Since these parts are being tested at a judiciously chosen stress level, the percent defective of the best parts may be relatively high and difference between it and the next best relatively large.

2
Procedure II

This is a quick method of separating several sources, populations, or vendors
into two groups, one of which contains the best source. One may state with confidence
P* that the parameter value (fraction effective) of each eliminated source is less
than that of the best population. Thus, when comparing 5 vendors with 10 sample items
from each vendor, the best vendor has a 90% chance of being among those vendors having
up to 4 more failures than the vendor having the fewest failures. For example, if a
vendor has 9 samples passing, include all vendors having 9-4 or 5 samples passing in
the better group. If all vendors have 5 or more samples passing, they are all in the
better group. Note: One to all vendors may be included in the "best" group depending
directly on the sampling results and indirectly on the true difference between them.
Thus, this is a coarse method of screening. This procedure may be followed by the use
of Procedure I if further screening is necessary. In doing this, it is assumed that
the experimenter will use new observations; otherwise one has to be concerned with the
effect on the probability of a correct selection of the procedure of carrying out two
tests on the same data.

TABLE I

Minimum number of observations required per process to guarantee a pro-
bability P* of a correct selection when the true difference d between
the proportions effective of the best and next best populations is at
least d*. The four values in each cell correspond to the probability
levels P* = .80, .90, .95, .99, respectively.

d*		fractional difference you wish to detect						
y	.05	.10	.15	.20	.30	.40	.50
2	142	36	16	9	4	3	2
	329	83	37	21	9	5	4
	541	135	60	34	15	9	5
	1082	270	120	67	29	16	10
3	273	69	31	17	8	5	3
	498	125	55	31	14	8	5
	735	184	82	46	20	11	7
	1308	327	145	81	35	20	12
4	359	90	40	23	10	6	4
	601	150	67	38	17	9	6
	850	212	94	53	23	13	8
	1442	360	160	99	39	21	13
10	606	151	67	38	17	10	6
	890	222	98	55	24	13	9
	1169	291	129	72	32	17	11
	1803	449	198	111	48	26	16

(Number of Populations being compared)

To apply Table II you must:

1. Decide on the probability level P* for the minimum probability of a correct
   selection.
2. Record the maximum number of samples "M" passing the test from any one of the
   several sources or vendors being compared.
3. Find the value of "d" in Table II for the sample size "n", the number of
   vendors "k" and the probability level P*.
4. Subtract the value of "d" from the maximum number of samples that passed
   from any one source.
5. Group all the sources or vendors together that have ("M" - "d") or more
   samples passing. These are the best sources and P* is the probability that
   the very best source is in the "better" group.

TABLE II

Values of "d" for Procedures II and IIIB to be used where there is a
common number "n" of observations from each of "k" populations. The
two values in each cell correspond to the probability levels P* = .90
and .95, respectively.

n \ k	2	5	10	15	20	25	30	40	50
				Number of Populations or Sources Being Compared					
5	2	3	3	3	4	4	4	4	4
	3	3	4	4	4	4	4	4	5
10	3	4	5	5	5	5	5	6	6
	4	5	5	6	6	6	6	6	6
15	4	5	6	6	6	7	7	7	7
	5	6	7	7	7	7	8	8	8
20	4	6	7	7	7	8	8	8	8
	5	7	8	8	8	8	9	9	9
25	5	6	7	8	8	8	9	9	9
	6	8	8	9	9	9	10	10	10
30	5	7	8	9	9	9	9	10	10
	6	8	9	10	10	10	11	11	11
35	5	8	9	9	10	10	10	11	11
	7	9	10	11	11	11	11	12	12
40	6	8	9	10	10	11	11	11	12
	7	10	11	11	12	12	12	13	13
45	6	9	10	11	11	11	12	12	12
	8	10	11	12	12	13	13	13	14
50	6	9	11	11	12	12	12	13	13
	8	11	12	13	13	13	14	14	14

(left margin label: Number of Samples from each Source)

2
Procedure IIIB

This procedure applies when the past history from one vendor or source called
"control" is not known and we wish to find other sources that are "as good as" the
control. This procedure guarantees with probability P* that all population or sources
as good or better than the control are classed "as good as" the control. Thus, when
comparing 5 vendors (one of which is the control) with 10 sample items from each ven-
dor we have a 90% chance of correctly classing vendors "as good as" the control if we
class vendors having 4 or less failures more than the control "as good as" the control.

Thus, if the control has 9 items (X_0) passing the test, all sources having 9-4
or 5 passing are classed "as good as" the control. Note: One to all sources may be
classed "as good as" the control depending on the sampling results obtained and in-
directly on the true differences existing. This is a coarse method of screening. To
determine which among the "as good as" sources is really best, use the sample sizes
required in Table I for the final screening based on new observations.

To apply the procedure, Table II is used:

1. Decide on a probability level P* for the minimum probability of a correct
   selection.
2. Record the number of items (X_0) passing the test in the control.
3. Find the value "d" in Table II for the sample size "n", the total number of
   sources "k" and the probability level P*.
4. Subtract the value of "d" from the number of items "X_0" that passed in the
   control sample.

5. Group all the sources or vendors as "as good as" the control that have "X_o-d" or more items passing the test.

Procedure IIIA[2]

A procedure to compare (with probability of a correct selection P*) several (k-1) sources or vendors with a source (control) having a known fraction effective (P_o) when (n) items are tested from each of the "k-1" sources.

Use this when the part history from one vendor or source called the "control" is known from incoming inspection records, factory rejects or field failures and we wish to find other sources that are "as good as" the control. Thus, if the fraction effective of the control is .90 (percent defective 10%) and we are comparing it with two other sources (k = 3) with 50 sample items from each of the other two sources, and if we desire a test with probability P* = .90 of a correct selection then 41 or more items must pass the test for either source to be classed "as good as" the control. The table for Procedure IIIA has been computed only for k = 2, 3 and 5. Note: In all cases, the value of k is the total number of populations involved and includes the control.

In Table IIIA an entry of zero indicates that the number of observations taken was not enough to separate out any inferior populations on the prescribed probability level.

To apply Table IIIA you must:

1. Record the number of items from each of the k-1 sources passing the test.
2. If the number of items passing is as large as or larger than the decision value in Table IIIA then class the source as "as good as" the control.

TABLE IIIA

Smallest integer value "M" required for Procedure IIIA for selected values of "n", P_0, "k" and P*. The three values in each cell correspond to "k" = 2, 3 and 5, respectively. P* = .90

n	P_0		Fraction Effective of "Control"						
	.10	.20	.30	.40	.50	.60	.70	.80	.90
5	0	0	0	1	1	2	2	3	4
	0	0	0	0	1	1	2	2	3
	0	0	0	0	0	1	1	2	3
10	0	0	1	2	3	4	5	6	8
	0	0	1	2	2	3	5	6	7
	0	0	0	1	2	3	4	5	7
15	0	1	2	4	5	7	8	10	12
	0	1	2	3	4	6	8	9	11
	0	0	1	2	4	5	7	9	11
20	0	2	3	5	7	9	11	14	16
	0	1	3	5	6	8	11	13	16
	0	1	2	4	6	8	10	12	15
25	1	3	5	7	9	12	15	17	21
	0	2	4	6	8	11	14	17	20
	0	1	3	5	8	10	13	16	19
50	2	6	11	16	20	26	31	36	42
	2	6	10	14	19	24	30	35	41
	1	5	9	13	18	23	29	34	41

(left side vertical label: Samples Tested From Each Source)

1961 ASQC CONVENTION TRANSACTIONS

TABLE IIIA

Smallest integer value "M" required for Procedure IIIA for selected values of "n", P_o, "k" and P*. The three values in each cell correspond to "k" = 2, 3 and 5, respectively. P* = .95

n	P_o	Fraction Effective of "Control"							
	.10	.20	.30	.40	.50	.60	.70	.80	.90
5	0	0	0	0	1	1	2	2	3
	0	0	0	0	0	1	1	2	3
	0	0	0	0	0	1	1	2	3
10	0	0	1	2	2	3	5	6	7
	0	0	0	1	2	3	4	5	7
	0	0	0	1	2	3	4	5	6
15	0	1	2	3	4	6	7	9	11
	0	0	1	2	4	5	7	9	11
	0	0	1	2	3	5	6	8	10
20	0	1	3	4	6	8	11	13	16
	0	1	2	4	6	8	10	12	15
	0	1	2	3	5	7	9	12	15
25	0	2	4	6	8	11	14	17	20
	0	1	3	5	8	10	13	16	19
	0	1	3	5	7	9	12	15	19
50	2	6	10	14	19	24	30	35	41
	1	5	9	13	18	23	29	34	41
	1	4	8	12	17	22	28	33	40

(Left axis label: Samples Tested From Each Source)

SAMPLE SIZES FOR OBTAINING REPRESENTATIVE SAMPLES [3]

Measurement Data:

A representative sample is a sample which faithfully reproduces the frequency distribution of the parent population. The degree of representativeness is a measure of how faithfully the sample reproduces the parent distribution. For practical considerations one has to limit the number of points at which the sample is compared with the parent distribution and also put a reasonable limitation on the degree of representativeness demanded.

The tables described here divide the population into two cells and determine representativeness relative to these two cells. The two cells may be formed by dividing the population in half by the median or by taking two percentiles symmetrical about the median such as the 10th and 90th, or 20th and 80th and paying attention only to the two tails of the distribution formed by these percentiles.

The faithfulness of the reproduction is given by B*, which is chosen so that with preassigned probability P*, a fraction between p-B* of the p+B* of the sample is below the population percentile p and also another fraction between p-B* and p+B* of the sample is above the population percentile 1-p.

The sample sizes are completely independent of the shape of the parent population.

Choosing a Representative Sample:

1. Decide whether the sample is to be representative relative to the median or the tails of the distribution.
    a. If relative to the tails decide how far out in the tails, 10th and 90th or 20th and 80th percentiles.
2. Decide how faithfully (B*) the sample must represent the population.
3. Choose the probability level P* at which this representation should take place.

Examples:

A) In testing the effects of radiation on transistor reliability, it is thought that the tails of the distribution are of most interest. Should you desire to be 99% sure that 5% to 15% of the sample be below the population's 10th percentile, the required sample size is 220 transistors. P* = .99; B* = .05; p = .10.

B) In testing the temperature coefficient of resistors, it is desired to have the sample centered about the population median so that you are 90% sure that 45% to 55% of the sample is above (and also below) the median. In this case, a sample size of 251 resistors is required to provide the stated assurance. P* = .90; B* = .05; p = .50.

TABLE V

Minimum Number of Units Required for a Sample to be Representative

P* \ B*	50th Percentile (Median) (p = 0.50)					20th or 80th Percentile (p = 0.20 or 0.80)					10th or 90th Percentile (p=0.10 or 0.90)		
	.01	.05	.10	.15	.20	.01	.05	.10	.15	.20	.01	.05	.10
.50	1,051	31	5	5	2	662	12	7	6	1	355	14	1
.60	1,700	60	5	5	3	1,062	32	7	6	1	500	14	1
.70	2,600	100	20	8	3	1,662	52	10	9	1	900	20	1
.75	3,251	120	25	11	3	2,062	72	10	9	1	1,100	40	1
.80	4,051	151	35	14	9	2,562	92	20	12	1	1,400	40	1
.85	5,100	191	45	17	10	3,262	120	27	12	3	1,800	60	1
.90	6,700	251	60	28	13	4,262	160	37	15	5	2,355	80	1
.95	9,551	371	90	37	20	6,100	232	50	20	10	3,400	120	10
.99	16,500	651	160	71	39	10,562	420	100	40	20	5,900	220	15

For n less than or equal to 150, the entries are exact; for n greater than 150, the entries are based on approximations and on a knowledge of the monotonicity pattern in each column.

SELECTING POPULATION WITH BEST MEDIAN[4]

We wish to compare two suppliers of the same type of transistor for I_{co} (reverse saturation current - collector to base) and need to know the number of sample units to be tested for I_{co} from each supplier (population or parent distribution in statistical language) in order to determine which supplier is best.

Let us assume we wish to be 95% sure of choosing the better source and our definition of "better" is that population whose cumulative distribution is at least d* better at all points within an interval + d* about the median. In this case we may desire that the better population be 15% better (which for I_{co} means lower) than the poorer population in an interval which extends from the 35th percentile to the 65th percentile of the better population.

The table tells us a sample of 63 units is required from each source.

To find the median, the measurements of I_{co} from each source should be ranked in numerical order. The median measurement is the 32nd in numerical order - an equal number of measurements are above and below it. Note that Table IV, on page 10 has only odd sample sizes.

To apply this table, certain decisions must be made:

1. Select the probability P* of correctly selecting the population with the "better" median. Better may mean higher or lower depending on the design needs. The cost of the test increases rapidly with increasing P* so do not ask for 95% or 99% accuracy unless you are willing to pay for it.
2. Choose the minimum distance d* between the percentiles that it is economically worthwhile to detect. This distance is in terms of the difference between the cumulative distribution functions through the chosen interval. As the sample size is an inverse function of the distance d*, it is best to choose d* as large as possible.
3. At the intersection of the distance d* and the probability p* in Table IV, we find the sample size which must be tested from each population.
4. The population producing the sample with the higher (or lower) median is the better population.

TABLE IV

d* P*	.05	.10	.15	.20
.50	21	5	3	0
.55	31	9	3	1
.60	47	11	5	3
.65	67	17	7	5
.70	95	23	11	5
.75	129	33	15	7
.80	181	45	19	11
.85	253	63	27	15
.90	363	91	39	21
.95	567	143	63	35
.99	1089	271	127	69

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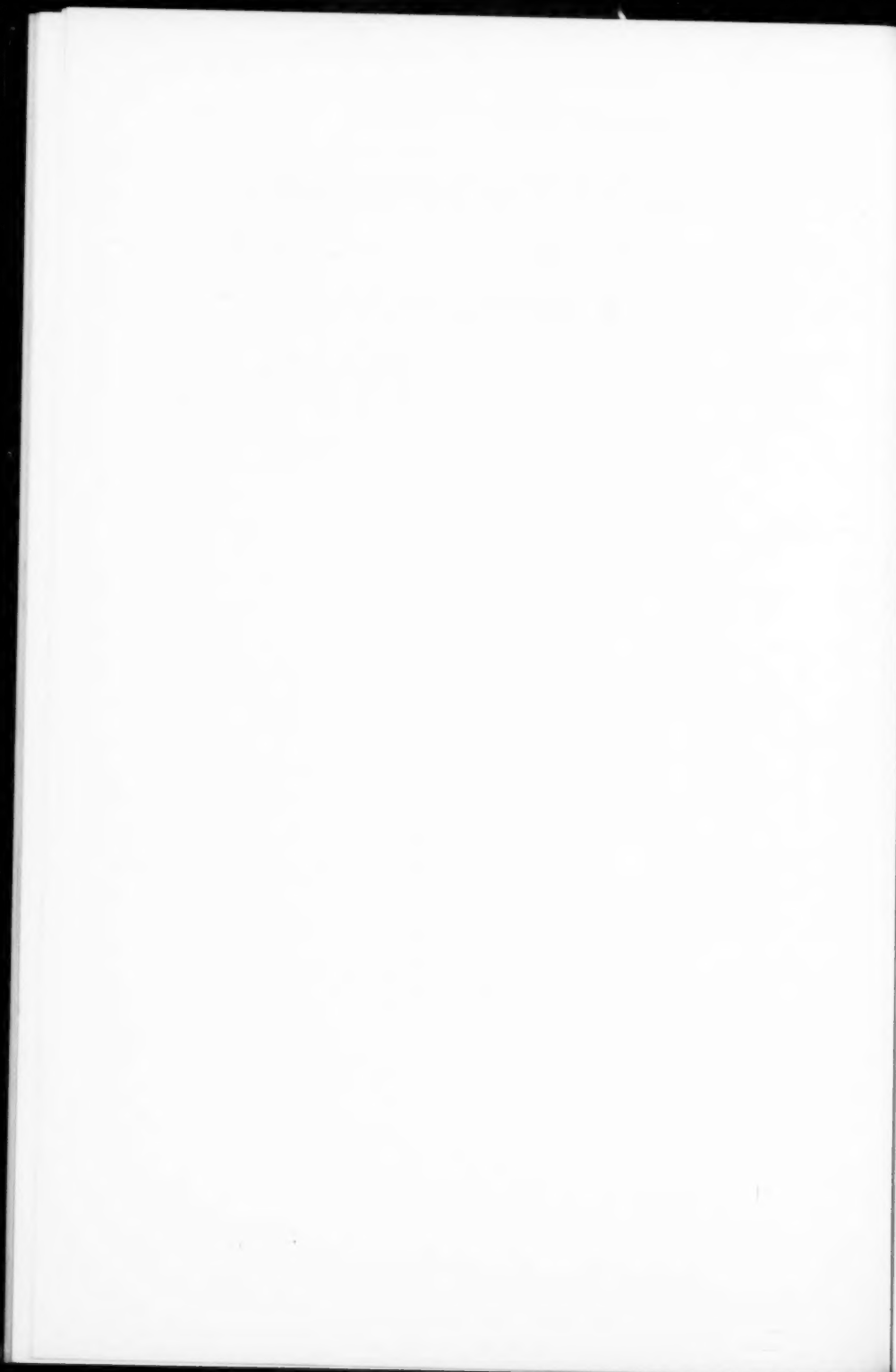
HUNTING AND TAMING THE WILD OBSERVATION

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$$x_1 \leqq x_2 \leqq \cdots \leqq x_n$$

      2.   Grubbs**
           paradigms:

(for 1 outlier) $\dfrac{S_1^2}{S^2} = 1 - \dfrac{n\,(x_1 - \overline{x})^2}{(n-1)\,S^2}$ where

$$\overline{x} = \Sigma x_1/n \text{ and } S^2 = \Sigma(x_1 - \overline{x})^2;$$

(for 2 outliers)

$$\frac{S_{1,2}^2}{S^2} = 1 - \frac{(x_1 - x_2)^2}{2\,S^2} - \frac{2n(\overline{x}_2 - \overline{x})^2}{(n-2)\,S^2}\ ,$$

where $\overline{x}_2 = (x_1 + x_2)/2$

   C.   Other Developments

      1.   A new approach: Anscombe***

      2.   Neutralizing protective coloration: Daniel****

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DESIGNING VALID EXPERIMENTS

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INTRODUCTION

The experimental approach to our environment is a well-ingrained human habit. We might observe that it is a lazy man's way of avoiding the necessity of thinking things through. However warranted the observation may be with respect to many of our day to day activities, experimentation is a strong and necessary support to theorizing in technology, where principles are grasped only darkly through our unaided senses. We might express concern that experimentation is so frequently only loosely connected with theory. We might not get very far on that tack either, because, as survivors of Nature's great experiment, most people seem to have the attitude that all the inept experimenters were eliminated when our would-be ancestors were testing the edibility of poisonous berries. We detect a cavalier attitude toward experimentation whether the outcome is likely to be lethal or not. We no sooner begin to feel good about the progress in use of experimental design throughout industry than we receive a shock from a communication like the following one:

> "The time involved plus the cost of testing in relation
> to the value of the information obtained pretty well
> precludes the setting up of test patterns based on
> statistical plans. Usually, we hold all but one factor
> constant because it is the variable that we are usually
> interested in. Consequently, we do not often get as
> exotic in our methods as might possibly be desired."

Such an attitude is based on unbounded confidence in an inate ability to plan experiments.

The paradox involved is that, like Nature, whose method of experimentation, natural selection, is careless of time or materials, the intuitive approach is so often unconcerned about the relationship between time and cost factors and the value of the information obtained. Neither by Nature nor by training have we been given to understand the real character of the physical world. It is only slowly that science and technology have awakened to the fact that it is not an exact but a probable world. In the face of the complexity of modern technology, our culture (the fault lies deeper than our educational system) has produced attitudes which have been altered little from those of the berry tasters.

A VIEW OF THE SCIENTIFIC METHOD

We hear a lot about the scientific method. As we understand its application to experimentation, it involves a number of steps which appear to be unpopular with many people. For instance, there is the insistence on formal, logical thinking about the pattern of experimentation. Certain intellectual groups have been trained in logic, but not the technologists. They are being forced into it by the machine, perhaps too lately. We already have bionic machines, with internal logic, which are self-adaptive, making adjustments in non-directed (somewhat random) manner by a process called "free learning."[1]

Then, there is the insistence on an understanding of the theoretical bases and the assumptions underlying the experiment. This involves recognition of experiment planning as being not a substitute for thinking, but an adjunct to thinking. It is a very lame excuse for poor experiment design to claim that time couldn't be spared for a proper one because the problem was one for which the boss expected the answers the day before yesterday.

Not infrequently, we come upon a person with the attitude that it is better to begin anew than to base experimentation on what has been done in the past. There may be some excuse for this because we have only begun to concern ourselves about efficient information retrieval. However, a scientific approach to experiment design implies taking full advantage of background data to help decide how much work to do or when to stop.

Finally, the scientific approach requires analytical skill, especially a gift for selection of fruitful questions to ask of Nature. For example, our berry-eating ancestors may have experimented with the relative digestibility of white or black pebbles with less drastic immediate effects than eating poisonous berries but with very little satisfaction as far as nourishment was concerned.

The scientific method in experimentation points not to a few pat patterns of testing but to general principles which apply to all aspects of the work.[2]

HOW EXPERIMENTATION WAS IMPROVED IN THE PAST

There are several ways in which experienced experimenters have attempted to improve the quality of experiment design. One way was to attempt to control all the variables not of interest to the experimenter. This approach broke down when the control was inadequate or when it could not be achieved at all. It also failed completely if unexpected or accidental variation arose.

Awareness of the shortcomings of the above approach has led to dependence on balancing and randomization to achieve the desired results.

Related to the concept of control of extraneous variables was the concept of changing the variables of interest to the experimenter one at a time while all the others were held constant. Many otherwise very capable experimenters seem unaware of the limitations of this approach although the sharper contrasts and the new information on inter-relationships among variables to be obtained simply by varying the experimental pattern scarcely need demonstration.

Another approach to improving experimentation was one which is very sound and which should be followed at all times. This was to analyze the sampling and testing techniques and to improve their precision prior to use. In every experiment, sampling and testing refinements should match the requirements of the situation.

Finally, another way used to improve an experiment was to increase the size of the experiment, that is make a larger number of repeated determinations under each set of conditions. Presumably, if we could afford to experiment without limit, eventually we could accumulate enough data so that the grand averages which we then could compare would disclose even minute differences in the effects of the factors we had varied.

EFFICIENCY IN EXPERIMENTATION

In a strict sense, the most efficient design is one in which the error variance has been minimized. In other words, an efficient design is one in which the variation in factors other than those under study has been controlled at a very low level. It is common to compare the error variance of a particular design with the variance that would have been expected had another design been used.[3] For example, Cochran and Cox provide comparative tables[4] and Fisher discusses methods of estimating efficiency.[5]

In a broader sense, efficiency may be taken to mean the degree to which the information derived from an experiment has been maximized for a given amount of work. From this angle, efficiency embraces several factors in addition to the relative size of the error variance. The number of experimental runs may be minimized; the comparisons that we wish to make may be sharpened; information on interactions may be enhanced; or the range of the factors studied may be increased. Measures of efficiency may include speed, economy, and administrative considerations.

Perhaps one of the most important attributes of the newer experimental designs being applied in industry is that they are designs with a purpose.

DESIGNS WITH A PURPOSE

There are two extremes of attitude that must be overcome. One is the attitude that nothing really amounting to a design is required or that a stereotype design, learned from a text or a "cook-book", is good enough for all occasions.

On the other hand, there are those who fasten upon one technique, often a relatively complex one, and seek to apply it universally, even to their simpler problems. There have been many specialized techniques made available to industrial statisticians. The authors of most of these have made the limitations clear and most users have applied them sensibly. In the long list of pet approaches, however, there are undoubtedly some which should be accepted guardedly and none which should be applied blindly under all circumstances.

If there is any danger, it is that the skill required to select the proper technique and to apply it correctly may be under-emphasized. Let there not be too much beating of the drums (the authors themselves are not always at fault) for new inventions. There is such a tendency to ride a hobby that those who have followed the development of industrial statistics may be able to associate names with the following mixture of excellent and indifferent techniques: multiple correlation, Latin squares (we have heard one well-known industrial statistician called a "pig-Latin square man"), partial factorials, random balance, lot-plot, span-plan, method of steepest ascent, response surface method, cumulative sum chart, evop (or even "revop"), and many others. They all have their place.

However, we recognize several separate and distinct purposes of experimentation, each of which may call for a different class of design. Among these purposes are:

(1) Making simple comparisons

(2) Testing the significance of changes

(3) Estimating the effects of changes, both in level of performance and in variation

(4) Moving toward optimum conditions

(5) Describing the relationships among variables by equations or plots

This list covers the span from limited objectives to all-out objectives. A design is evaluated, not by its complexity but by its ability to solve a particular problem. Refined statistical designs are by no means the only ones that pay off. It sometimes happens that intuitive designs, not at all sophisticated statistically, pay off handsomely. In other instances the statistical planning required is rudimentary because of the simplicity of the experimental situation.

A design of great complexity standing alone may not be as desirable as a series of less ambitious designs that sequentially add to our knowledge. It is common practice to use brief, preliminary experiments in scouting for primary effects, followed by more complete designs covering the important variables. A good design is one which lends itself to extension.

Several examples follow in keeping with the thesis that every experiment must be designed with a purpose.

EXAMPLES OF DESIGN WITH A PURPOSE

Example I. The vibrational problems in complex equipment, such as rockets, are well known to the developers and users of the equipment. It may be surprising to hear that vibrational problems plague manufacturers of as staple a material as paper. Breaking of the paper web in a high speed

printing press is annoying and can lead to publication delays and even
to breakage of the press.   n an instance in which web breaks were
occurring at an alarming rate, a systematic analysis was undertaken in
order to determine the causes. One design for data collection involved
totalling the web breakage rate on rolls of paper shipped by rail versus
rolls shipped by water. A higher web breakage rate was found for rolls
shipped by rail. The explanation offered was pre-stressing by the con-
stant vibration during rail-shipment of the rolls of paper which had
been wound under tension. The end of each roll was pasted down, main-
taining the tension. The pre-stressing weakened the web. The solution
was to wind the rolls under less tension and to allow plenty of slack
in pasting down the ends. The web breakage rate on rolls shipped by
rail decreased.

Example II. Aero-space materials improvement is of interest to both the
military and industry. One of the ways to improve materials is to im-
prove specifications. There is a particular interest in adequate speci-
fications for some of the newer non-metallic, ceramic materials, inclu-
ding many of the carbides, nitrides and borides. It is helpful to obey
certain principles in establishing specifications: simplify - both
the design of a part and the choice of characteristics for measurement;
apply direct rather than indirect tests; avoid lengthy and costly fin-
ishing operations; and don't over-specify. In the non-metallics, fin-
ishing problems control, whereas in metals, dimensional stability con-
trols; in the former, compressive strength controls, in the latter,
tensile strength controls. The user will probably require evidence of
process and of laboratory control. The latter, in particular, will
require the design of experiments. These will be designed with the
purpose of making a precise statement or certification of the nature,
"With 95% confidence, it is certified that not less than 99% of the
material delivered has a density (or some other property) of X g/cc."
When valid experiment designs are not their source, the data available
are usually inadequate.

Example III. Power spectrum analysis is valuable for study of rocket
flight data and equally valuable for analysis of testing of commercial
materials ultra-sonically. A specialized application is study of the
surface characteristics of coated abrasives. Purposeful designs are
necessary to obtain data that can be subjected to available techniques
of analysis. In this instance, devising a method of measurement and a
method for collecting the data tax the ingenuity of a combined team of
engineers and statisticians. Optical projection techniques have been
combined with manual tracing of profiles and counting of included areas
or combined with electronic scanning with a digital read-out. Horizon-
tal scanning and vertical scanning have both been applied. Photographs
of profile and plan of the material have been substituted for optical
projection. Contact photography, optical displacement of photographic
negatives, densitometer readings of impressions on thermo plastic tape,
reading of mirror-images picked up on film and x-ray photography are
other experimental data gathering techniques that have been explored.
Other even more complex methods of granularity measurement have been
proposed. The resultant data is often in the form of waves of very
low frequency. Keen experiment design is needed to collect the inform-
ation in useable form.

Example IV. Certain kinds of experiment designs lead to particular methods
of data analysis. For example, a factorial design leads to use of
analysis of variance or response surface experimentation leads to matrix
solution of regression relationships. When factorial experiments are
applied to some problems, the effects of the independent variables on
variances rather than on means are of interest. In this instance some
additional treatment of the data such as transformation to logarithms
may be desirable prior to use of the analysis of variance. In response
surface experimentation, the analytical techniques lend themselves to
variable measurements but not, at least at present, to psycho-physical
attribute data. For example, in an experiment to optimize the density
of a new abrasive material, two responses were recorded: measured
density and a visual classification of porosity on an arbitrary scale
from one to four. Response contours could be computed for the measured
density. However, it would have been improper and misleading to have

analyzed the porosity data in the same way. Design with a purpose puts emphasis on planning for collection of data in appropriate design patterns and with suitable method of data analysis in mind.

Example V. A typical experiment involving dimensional restrictions is the sampling of bulk material as in a box car. A grid pattern is super-imposed on the plan of the car and a sampling thief is inserted in the material in the car at each grid intersection. Duplicate samples should be taken at each location to provide a measure of experimental error. Lengthwise and crosswise arrays of measurements correspond to columns and rows in a two factor analysis of variance. The purpose is to detect any heterogeneity in the material, due to loading practices, or segregation of particle sizes, due to vibration during transportation. In some instances, the possibility of differences at different depths is also of interest, and a third dimensional factor is added to the experiment. Since dimensional locations are fixed, one cannot get away without duplicate samples. As an end result of such a procedure an economical sampling plan, which will give desired protection against off-grade material, may be selected.

Example VI. A more difficult problem involving dimensional restrictions arises in the characterization of sheeted materials or in sampling of these types of materials for process control. Certain types of grinding wheels are pressed from material which is a fibrous sheet in which abrasive grits have been embedded during the manufacturing process. A typical problem may be determining weight per unit of material died out with specified dimensions. The material is supplied in rolls from which sheets are cut. Discs are then died out from the sheets. The weight variations that are of interest include variation across the sheet, in adjacent positions in the long direction, at the extreme ends of the cut sheets, from sheet to sheet within a roll, and from roll to roll. Obviously, only one sample can be cut from one position, so that replication in the true sense is never attained. Cause systems affecting weight across the sheet and in the length direction are different. The variation across may consist of a bias, rather than random variation, although random shifts in weight may be characteristic of some making machines. Variations in the length may be random, or cyclic (from a few inches to many yards), or may indicate long trends (even seasonal ones). In planning experimental data, the natural tendency is to take samples from fixed positions. For some purposes this is desirable. Consideration should also be given to random sampling and what this will do to the model of the experiment. Proper selection of sampling interval is important. It may be desirable to take into account principles applying to power spectrum analysis, for example, the 'Nyquist' sampling interval which requires equidistant sampling at least twice in the interval of the shortest harmonic of interest. There is a 'Bicking' interval which calls for random sampling at least once in every cycle or if the cycle frequency and shape are not known, at least as often as the expected number of cycles. The Nyquist sampling implies Fourier analysis, random sampling a least squares approach, or autocorrelation. None of these methods of analysis are generally associated with sampling on a factorial plan.

Example VII. If we are going to use indirect measurement (for example, density of a molded silicon carbide body), rather than a direct measurement (per cent SiC in the body) we are asking for more work when we start to combine experimental results for the purpose of writing a specification or making a certification statement. So, it becomes of importance to be purposeful in the designing of experiments to collect data with the end-use in mind. The same thing is true of combining variance data from different sources. Combining variances, and particularly estimating degrees of freedom for the result, have involved laborious computation in the past. The problem can be avoided, in the first instance, by using only direct measurement where this is at all possible. Explicit designs to measure variation from several sources simultaneously are of help in the second class of situations. Tables of Tolerance - Limit Factors for Normal Distributions now cover the situation where the total variance is made up of components from various sources. With the increase in contractual requirements for the certification of quality, it is important to design experiments taking factors

such as these into account.

Example VIII. In some instances, it is desirable to know all the relationships among two or three independent experimental factors as they affect one or more dependent factors or responses. For example, in developing a free-flowing, storable temporary binder for use in the molding of vitrified grinding wheels, it was desired to determine the influence of size of grit, of per cent bond, and of inorganic density, each over the usual range of manufacture. These variables could affect several finished product properties, including hardness, density, and response to ultra-sonic vibration. A three factor central composite rotatable design was used with six replications of the center point (paired randomly throughout the run). It is possible to obtain complete sets of equations representing this system for each of the three responses. Also, a plotting routine on an electronic computer prints out for each product property, the response contours for each of the three pairs of independent variables. The whole bonding system is much better understood than it ever was before. Optimum formulations may be picked from the charts and combinations resulting in poor product quality can be avoided.

CONCLUSION

A valid experiment design is one that applies statistical principles for the achievement of a specific purpose. There are several very good texts available as sources of designs.[3][4][6] Skill must be developed in selection of the technique and in its correct application. The design may be very complex or it may be so simple that no special skill was required to plan it. Nevertheless, the purpose of the design will be served best if it matches the situation and if it lends itself to statistical analysis.

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RESPONSE SURFACE TECHNIQUES AS A STATISTICAL APPROACH
TO RESEARCH AND DEVELOPMENT IN ULTRASONIC WELDING

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INTRODUCTION

Statistical designs and analyses have been very useful at Aeroprojects in research on and development of a new and unique process, underlined ultrasonic welding. Particularly useful are the methods of fitting response surfaces and the locating of optimum operating conditions as developed by Box & Wilson, Hunter and others. These methods are applied to experiments in welding programs, and involve the use of specific statistical designs such as factorial or fractional factorial, hexagonal, central composite, etc., i.e., designs of two or more variables. The statistical analysis of the results provides an estimate of the response surface or contours, and shows the relationships between the independent results (strength of weld) and the controllable factors (power, clamping force, etc.). Such an analysis also gives the direction of "steepest ascent" of the contour that is used in estimating the best levels of the variables so that, in subsequent experiments, still greater strength of welds may be obtained. Some specific examples of these methods will be presented together with the surfaces fitted to the data.

All experimentation at Aeroprojects is accompanied by standard quality control techniques. We recognize that the experimenter"often neglects the inherent causes of unreliability. He is inclined to believe that reliability is an ability -- whereas, in fact, it is only a probability"(11)*. By means of statistical methods, the intuitive type of reasoning which an intelligent experimenter might apply in drawing inferences from data is made objective and precise.

ULTRASONIC WELDING

Ultrasonic welding is a non-fusion, solid state process for joining similar and dissimilar materials by the introduction of high-frequency vibratory energy into the area to be joined (13). A strong metallurgical bond is produced without the aid of solders, fluxes, or filler metals, without the external deformation that characterizes pressure welding, and without the cast metal zones associated with resistance welding. The process has been successfully applied to spot-type welding, spot-seam welding, continuous-seam welding, and area welding (15, 16, and 17).

Several types of machines are available. Figure 1 illustrates a precision 100-watt capacity ultrasonic welding machine used for joining foils, fine wires, and semiconductors (such as silicon). This unit is particularly applicable to the delicate welding problems encountered in the transistor construction field. Figure 2 shows the most recent and largest ultrasonic welding machine designed for commercial use.**
This welder is capable of welding structural gages of such metals as aluminum and stainless steels.

RESPONSE SURFACE TECHNIQUE

A brief explanation of the response surface fitting techniques may be helpful. With two controllable independent variables (such as power and clamping force), and a dependent resultant variable (such as shear strength), it may be possible to obtain several types of configurations or surfaces such as shown in Fig. 3, where shear strength is represented by the contour lines graphing the surface. The response function of two variables represents a sketch of a three-dimensional function in two dimensions. This simplified presentation of a contour map, which projects sections

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*Numbers in parentheses refer to the list of references at the end of this paper.

**These ultrasonic welding machines are manufactured and sold by Sonobond Corporation, a Subsidiary of Aeroprojects Incorporated. Further information on these and other ultrasonic welding machines can be obtained from Sonobond Corporation, 202 W. Market Street, West Chester, Pennsylvania.

Fig. 1: SONOWELD® MODEL W-100-TSL   Fig. 2: SONOWELD® MODEL W-4000-FSR

of the three-dimensional surface on to a two-dimensional plane, appears easier to draw and simpler to understand.

The Figures are typical response surfaces on ultrasonically welded specimens that have been estimated from experimental results obtained by using statistically designed experiments such as those presented in Fig. 4.

The design in Fig. 4A is a 2 x 2 or 2^2 factorial, with two levels of each of two variables. Figure 4B is a simple cube or "Box" using two levels of each of three variables, sometimes called a 2^3 factorial. These are first-order experimental designs with replicated center points.

When it is necessary to determine the response as a function of several controlled variables over a wide range of these variables, a second-order experimental design should be used. Two such designs are represented by Fig. 4C and Fig. 4D.

For a more detailed explanation of the technique of response surface fitting, including the Doolittle Technique (4), see Davies, "The Design and Analysis of Industrial Experiments" (2).

ADVANTAGES OF USING A STATISTICAL DESIGN EXPERIMENT

According to Besse Day (6, 7, and 8), the chief characteristics of statistical designs are the inclusion of multiple factors within some test at more than one level, and the randomization of all possible sources of variation, including order of testing.

The resultant advantages that these characteristics provide are as follows:

    (a) A valid base for computing the numerical uncertainty of inferences drawn from the experimental data
    (b) A gain in the precision of estimates
    (c) A greatly enhanced scope of conclusion
    (d) A substantial saving in cost
    (e) An increased sensitiveness leading to the detection of small real differences which otherwise might not be evident.

It is also possible to measure not only the effects of factors at various levels, but also the joint effects of the factors. If we use the classical approach of investigating one factor at a time, we may be measuring effects and assigning their cause to the specific variable under investigation when in reality we are measuring the influence of variables which are not as yet known. Dr. Hunter (4) has given a graphic illustration of the favorite and classical approach of varying one factor at a time while holding all others constant. He also has shown that in using this approach, the experimenter may completely miss the maximum if a certain type of response surface exists. For instance, if the surface shown in Fig. 3B exists, the experimenter may use a constant 140 watts and vary the clamping force until a maximum of 60-lb shear strength is obtained at about 200-lb clamping force. Then, keeping the clamping force constant (at 200 lb) he may increase power by steps from 140 watts to 600 watts, thus reaching a maximum shear strength of 87 pounds. However, a 100-lb shear strength level
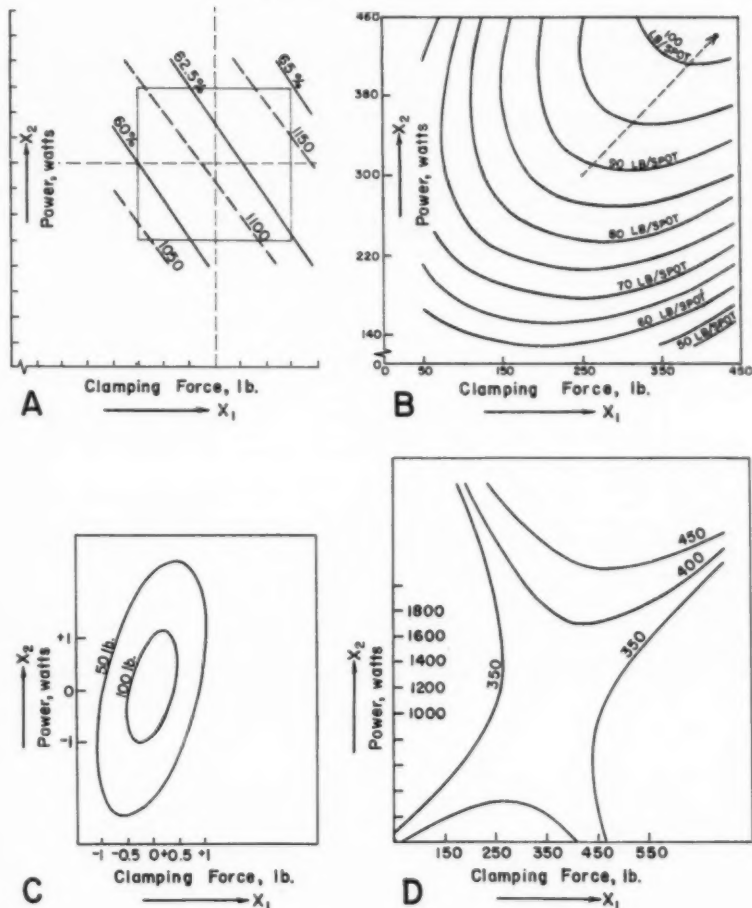
Fig. 3: TYPICAL RESPONSE SURFACES OBTAINED
WITH ULTRASONIC WELDING DATA

could be arrived at by use of a statistical design with "steepest ascent" approach. Thus, by means of planning, and by establishing a statistical design, it is possible to gain increased precision, to broaden the scope of the conclusions, and to obtain more information from the same amount of experimentation (or a decreased amount of experimentation with resultant saving of time and money).

RESPONSE SURFACE TECHNIQUES AS USED IN ULTRASONIC WELDING

An Ultrasonic Welding Program at Aeroprojects, whether research, application engineering, pilot-plant services, or production of welding equipment, involves the following procedures:

1. Statistical design of experiments

2. Statistical analysis of data

3. Routine quality control.

1.   Statistical Design of Experiments

In general, the experimenter and the statistician must precisely state the objectives and possible outcomes of the experiment. It is important that the statistician have a knowledge of the details of the proposed project. Then the experimenter and the statistician, working together, screen all possible variables and eliminate all but the most important. The cardinal rule, as stated by Crawford (10), is to use statistics in the planning stage. The experimental design, i.e., the number, spacing, replication, and interrelationship of the individual experimental trials, should be correctly chosen.

In choosing the pattern for each experiment, after the scope and objectives have been formulated, the possible experimental testing levels for major variables are estab-
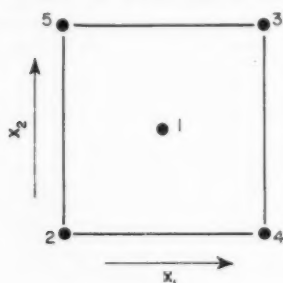
A   Two-Variable Factorial (2^2) Design
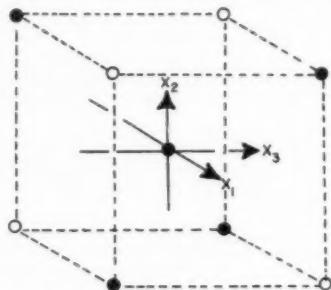
B   Three-Variable Factorial (2^3) Design With Replicated Center Points
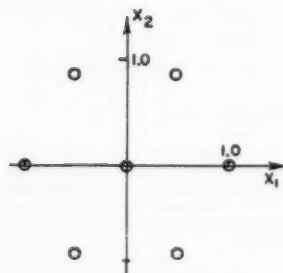
C   Hexagon Design
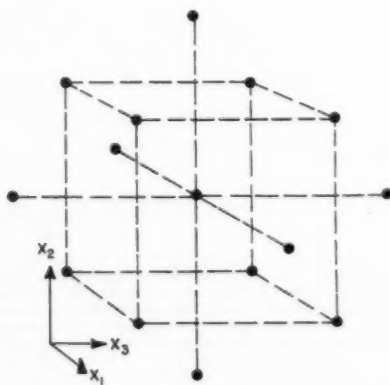
D   Central Composite Design

Fig. 4:   EXAMPLES OF STATISTICAL EXPERIMENTAL DESIGNS

lished jointly by the experimenter and the statistician. In judging the amount by which a factor should be varied in the experimental design, the experimenter is attempting to get as near as possible to the maximum response indicated in the relationship between the variables. Of course, when a second experiment is carried out, the statistician has some basis for determing the relationship of the factors. With ultrasonic welding, the relative scales for each variable are fixed by the judgment of the experimenter and statistician when they decide the relative amount by which the factors will be varied in the experimental design. Skillful choice of the amount by which the factor should be varied will considerably reduce the amount of subsequent work. It must be emphasized that the choice of ranges to be used on each variable is by no means governed by rule of thumb; rather, experience and judgment must play an important part in this procedure. The reproducibility of the variables should influence the choice of scales; e.g., the better the reproducibility, the smaller the intervals. In ultrasonic welding, the properties of the material being welded are a deciding factor.

2.   Statistical Analysis of Data

Statistical Analysis of the data includes the fitting of response surfaces, testing for "goodness of fit", and finding the proper levels of each of the variables used that result in the greatest strengths possible with a good weld (this last uses the method of steepest ascent on the fitted contour to point to levels for further experimentation). This technique is best described by a few examples which show the designs used, the statistical process used in fitting the response surface by the Doolittle Technique, the resulting surfaces or contours in both graphical and equation form, the testing of these surfaces for "goodness of fit", and the calculations that determine the direction of "steepest ascent".

The path of "steepest ascent" technique assumes that a plane can roughly approximate the true curved surface in a limited area. The tilt of the fitted plane can then suggest the direction of further experimentation. For the sake of brevity, a very simple 2^3 (3 factors at 2 levels each) experiment has been chosen to demonstrate the type of calculation used. The example gives a diagram of an experimental design where the vertices of the cube indicate the machine settings of power, force, and time. The four solid dots in the vertices of the cube show the half-factorial; the circles designate the other half-factorial which could be used. The calculated example presents the actual machine settings for each experimental point as well as the coded machine settings, or X values. Also presented are the coded Y values (shear strength response values), the sum of the response measurements, and the differences for the two replicates.

First-Order Experiment with Three Controlled Variables
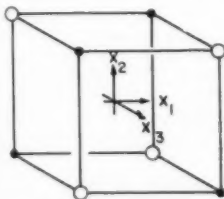
A 2^3 factorial design showing the division into two half-replicate designs.

Mathematical model $y = \beta x_0 + \beta x_1 + \beta x_2 + \beta x_3 +$

	Factor Levels			Matrix of Independent Variables			Vector of Observations (Coded)*			Experimental Error
							Shear Strength Y			
x_1 Force, lb	x_2 Power, w	x_3 Time, pulse	x_0	x_1	x_2	x_3	Replicates No. 1	No. 2	lb Σy	(Y_1-Y_2)
750	3200	1.5	1	1	1	1	91	91	182	0
750	3200	1.0	1	1	1	-1	79	80	159	1
750	2400	1.5	1	1	-1	1	84	85	169	1
750	2400	1.0	1	1	-1	-1	40	63	103	23
550	3200	1.5	1	-1	1	1	71	89	160	18
550	3200	1.0	1	-1	1	-1	80	80	160	0
550	2400	1.5	1	-1	-1	1	78	78	156	0
550	2400	1.0	1	-1	-1	-1	72	69	141	3

Error = $\Sigma(Y_1-Y_2)^2$

$\dfrac{864}{2} = 432$

Forward Doolittle: Convenient procedure to solve simultaneous equations
Design set up for easy solution of Coefficients (Code Y values)

b_0	b_1	b_2	b_3	b_0	b_1	b_2	b_3		
N	Σx_1	Σx_2	Σx_3	16	0	0	0	$1230 = \Sigma y$	or $16b_0 + 0b_1 + 0b_3 = 1230$
	Σx_1^2	Σx_2	$\Sigma x_1 x_3$	16	0	0	$-4 = \Sigma x_1 y$	or $16b_1 + 0b_2 + 0b_3 = 4$
		Σx_2^2	$\Sigma x_2 x_3$	16	0	$92 = \Sigma x_2 y$	or $16b_2 + 0b_3 = 92$
			Σx_3^2	16	$104 = \Sigma x_3 y$	or $16b_3 = 104$

Proceed by dividing all
the elements by the lead-
ing element, as follows:

						Sum of Squares
Row 1	16	0	0	0	1230.000	
(Eq for b_0)	1	0	0	0	$76.875 = b_0$	$b_0 = (1230)(76.875)$
						"Correction factor"
Row 2		16	0	0	-4.000	
(Eq for b_1)		1	0	0	$-0.250 = b_1$	$b_1 = (-4)(-0.25)$
Row 3			16	0	92.000	
(Eq for b_2)			1	0	$5.750 = b_2$	$b_2 = (92)(5.75)$
Row 4				16	104.00	
(Eq for b_3)				1	$6.50 = b_3$	$b_3 = (104)(6.5)$
						Estimate of the Coefficient

Using the coded parameter, the equation for the
plane is as follows:

Shear Strength $Y = 76.875 - 0.25X$ (force) $+ 5.75X_2$ (power) $+ 6.5X_3$ (time),
within the limitations of this first experiment.

Regression Analysis Table: Tabled Variance 5%

	SS	df	MS	$\hat{\rho}$	Points of $\in^{2z}$ Ratio
y^2	96,928.00	16			
b_0	94,556.25	1			
b_1, b_2, b_3	1,206.00	3	402.00		
Residual	1,165.75	12			
Lack of fit	733.75	4	183.4375	3.397	$F_{4, 8} = 3.84$
Error	432.00	8	54.00		

Observe that the lack of fit mean square is not significantly different
from the experimental error mean square at the 95% probability level.
The outcome of this experiment is merely to have some basis for designing
a second experiment.

Calculation of Path of Steepest Ascent and Subsequent Trials on the Path:

		x_1, Force	x_2, Power	x_3, Time	
(1)	Base Level	650.00	2800	1.25	Average Y, shear
(2)	Unit	100.00	400	0.25	strength = 768.75 lb (not coded)
(3)	Estimated Slope b (change in yield per unit)	-0.25	5.75	6.5	
(4)	Unit x b	-25.0	2300	1.625	
(5)	Change in level per 400 w change in x_2	-4.4	400	0.28	
(6)	The path of steepest ascent represented by a series of possible trials on it	650.0	2800	1.25	
		645.6	3200	1.53	
		641.2	3600	1.81	
		636.8	4000	2.09	

*Coded Response (Y - Response divided by 10)

The Doolittle solution of this design is a convenient method of solving the simultaneous equations that are used to obtain the response surface. Note that the design is set up with zeroes for an easy solution of the coefficients. The calculations generally follow the procedure outlined in Davies (2).

Experimentation with various materials and thicknesses has established that the relative influence of controlled variables and their appreciable interaction effects are specific for each type of weld (one relationship for Al to Al, another for Cu to Al, Ti to Ti, Ti to steel, etc.). A minimum of observation and a complete evaluation of weld quality by means of nondestructive x-ray, and measurements of weld area, cross-tension, percent deformation, and tensile-shear strength, points the way to subsequent trials from a first, fully designed experiment. The amount of repetition necessary is based on the known variability and on the cost of the first experimentation.

Some specific experimental designs and resulting contours are included in Fig. 5, 6, and 7, and illustrate the use of the methods of response surfaces in ultrasonic welding.

Figure 5 uses a 3 x 5 factorial in order to obtain the contour indicated by the equation. The volume of experimentation and the calculations are quite detailed in a factorial with 15 experimental points.
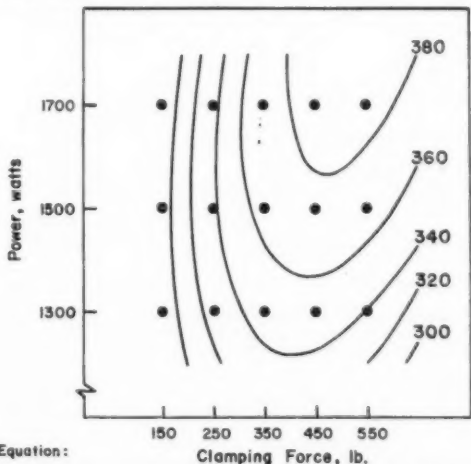
Calculated Equation:

$$\hat{y} = 363.8703 + 36.7666X_1 + 11.7500X_2 - 32.8204X_1^2 - 5.4442X_2^2 + 12.5500X_1X_2$$

Estimate of Lack of Fit: $F_{9,31} = 1.17$ ($F_{9,30} = 1.50$, 80%)

Fig. 5: AN EXAMPLE OF A RESPONSE SURFACE OBTAINED FROM A FACTORIAL-
DESIGNED EXPERIMENT SHOWING LEVELS OF TENSILE-SHEAR STRENGTH
FOR 0.020-INCH COPPER (HALF-HARD)

Figure 6 shows a rotatable hexagonal design (indicated by the dots), which gives the results at each type of weld in pounds tensile-shear strength. An experimental design possessing equal predictability in all directions from the center of the design at a constant distance from the center is called a "Rotatable" design. The center point is replicated more frequently than the peripheral points in order to provide an estimate of the experimental error. Replicating the center point also insures good predictability toward the center of the design.

It is a great satisfaction to be able to determine whether or not the fitted model is a proper one, or how well the proposed mathematical model fits the data. The model presented in Fig. 6, is an excellent fit, $F_{1, 10} = 0.1227$. Tabled value of the F- distribution ($\alpha = 0.50$, $N_1 = 1$, and $N_2 = 10$) equals 0.48973. Of course, this is a limited experiment, and the F value from an analysis of variance compares the fitted surface variance, which has 1 degree of freedom, with the error variance which has 10 degrees of freedom.
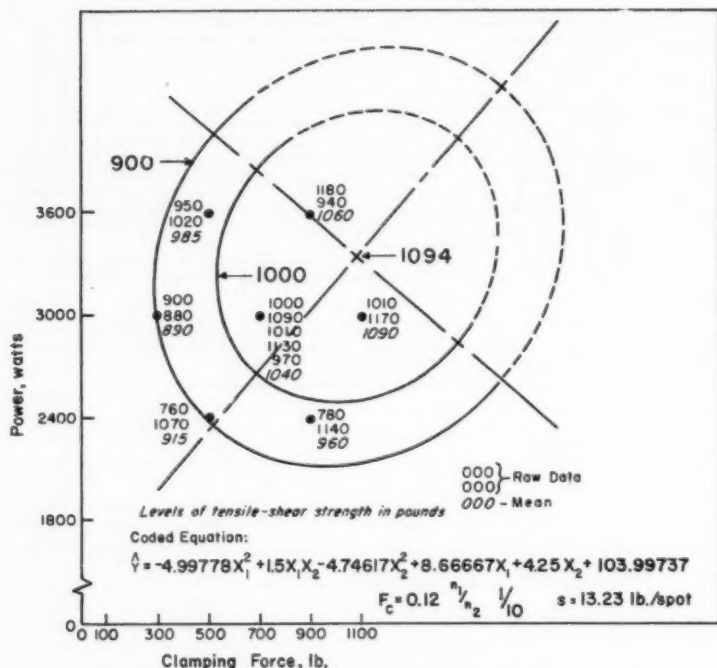
Fig. 6: AN EXAMPLE OF A RESPONSE SURFACE (ROTATABLE HEXOGONAL DESIGN) OBTAINED AS A RESULT OF THE BI-METALLIC WELDING OF 0.063-INCH COPPER TO 0.032-INCH ALUMINUM

In the examples presented the machine settings indicated are not necessarily optimum settings; rather, the settings represent experimental problems that have been studied to determine those few controlled variables which have the most profound effect on ultrasonic welding.

An interesting experiment with welding of molybdenum to itself (Fig. 7) evolved when a rotatable hexagonal design was used with five levels of clamping force and three levels of ultrasonic power. The contours of the first experiment indicated a significant fit of the second-order mathematical model.

The region of wide variability and microscopic evidence of inferior quality weldments were concentrated in the peripheral experimental points of the hexagon. The first experiment indicated that crack-free welds of acceptable strength could be obtained in the center of the experiment. This indication was affirmed with a larger sample as well as the photomicrograph as shown in Fig. 7. A second experiment which involved a large sample at each point on an equilateral triangle within the original experiment verified the original data. The only region where high quality welds were obtained was within the elipse enclosing the center of the experimental region.

Ralph Waldo Emerson once said: "Bad times have scientific value. These are the occasions a good learner would not miss." Poor quality welds in some regions provide as much information as the actual knowledge of the region in which we can obtain good quality welds.

Figure 8 illustrates how the experimental results can be presented to the experimenter in a simplified and complete form. The response surfaces may be shown on a separate graph. This illustration is primarily for the experimenter, with the actual weld-
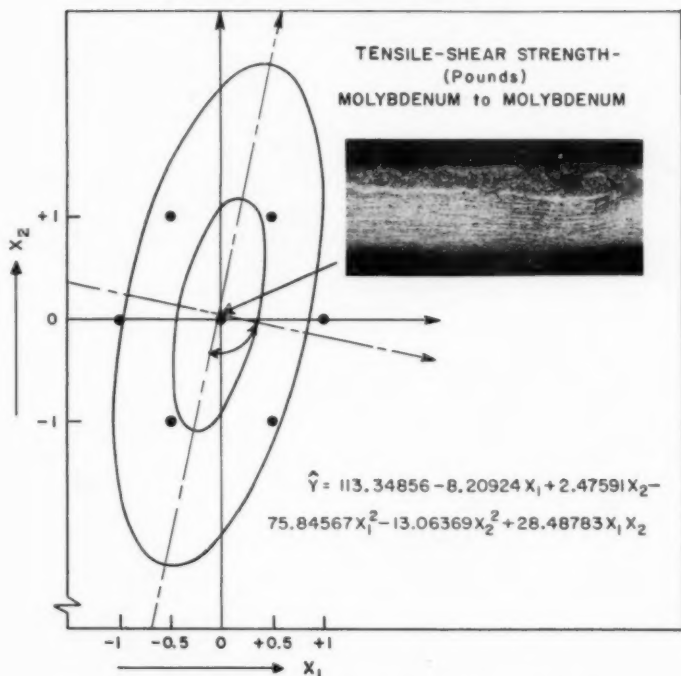
Fig. 7: A RESPONSE SURFACE (ROTATABLE HEXAGONAL DESIGN) OBTAINED
AS A RESULT OF WELDING MOLYBDENUM TO MOLYBDENUM. OPTIMUM
RESULTS WERE CONCENTRATED IN THE CENTER OF THE ELIPSE.

ed specimens (A) mounted in relationship to the experimental design. The photomicro-
graphs (C) provide complete information about the experimental region that results in
poor quality welds, as well as the region that produces high quality welds. Part B of
Fig. 8 presents the design levels and the various measurements obtained at each respec-
tive experimental point. These various results aid the experimenter and the statisti-
cian in establishing standards and in subsequent welding.

3. Quality Control Techniques Used in Ultrasonic Welding

Improvements in the ultrasonic welding equipment from time to time, in an effort
to establish an acceptable standard, have been accompanied with continuous statistical
quality-control charts on shear strength. Statistical tests of significance have shown
that shear-strength measurements follow the normal distribution pattern. The selec-
tion, control, and sensitivity of routine performance tests are considered and char-
acterised by one or more parameters such as means and standard deviation. Low vari-
ability in the tensile-shear strength measurements indicates that proper engineering
has produced welding equipment which provides consistent, high quality welds that will
function satisfactorily for the purpose intended. This low variability, as measured
by the standard deviation, is induced by constant checking with control charts. In all
instances, the points that fall outside the plotted control limit are investigated. In
one case the component parts of a transducer-coupling system had to be re-worked be-
cause the variation in welds it produced was greater than should be expected. This is

NICKEL- 0.008 IN.

$$\hat{y} = 1994 + 31.22X_1 + 17.73X_2 + 4.87X_3 + E$$

TENSILE SHEAR STRENGTH
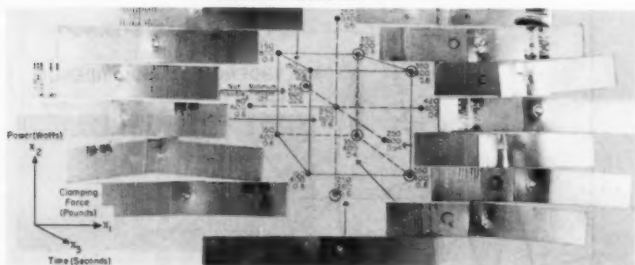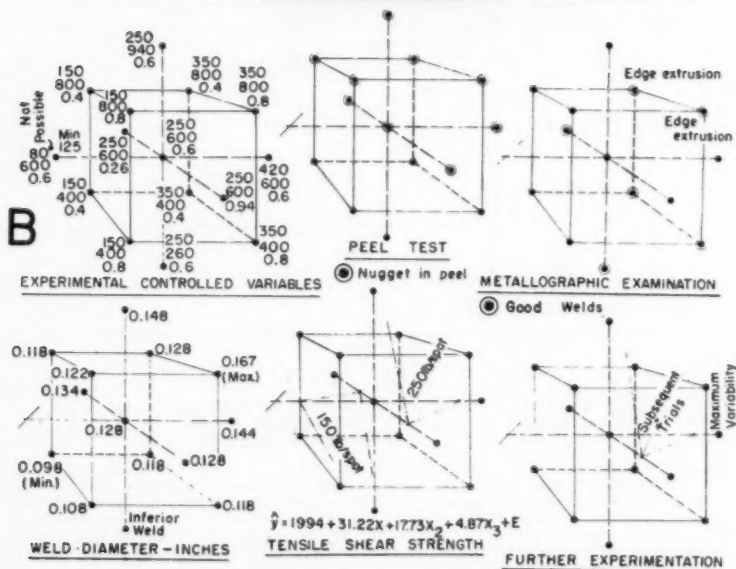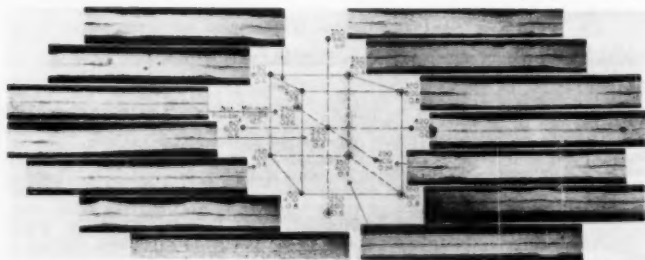
Fig. 8: PRESENTATION OF INFORMATION (OF INTEREST TO THE EXPERIMENTER) OF AN INITIAL EXPERIMENT THAT WAS USED TO OBTAIN PERFORMANCE DATA WITH LIMITED EXPERIMENTATION OVER A WIDE RANGE OF MACHINE SETTINGS

illustrated in Fig. 9, and 10, which show the results of data obtained on four identical models of machines that were being tested to determine whether or not they would meet the specification limits established for this class of welders. Welder No. 2 did not meet this specification. The first testing resulted with a mean value of 790-lb shear strength, and a standard deviation of 177 lb. This unit was returned to the Fabrication Shop, and after modifications, the performance level of this unit, as indicated in Fig. 9, maintained a mean value (990 lb) equal to the best machine; also, this unit had the lowest standard deviation of the four machines tested.

Fig. 9:   MEAN TENSILE-SHEAR STRENGTH, lb, FOR
2024-T3 BARE ALUMINUM, 0.040 INCH*
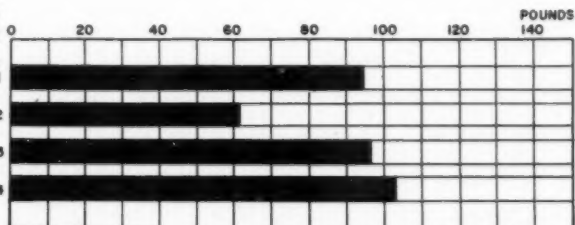
Fig. 10:   STANDARD DEVIATION OF TENSILE-SHEAR STRENGTH, lb
2024-T3 BARE ALUMINUM, 0.040 INCH

SUMMARY

Statistical techniques and designs in fitting response surfaces have been particularly useful in research and development of ultrasonic welding at Aeroprojects Incorporated. These methods have been particularly useful in differentiating between the operating conditions that produce high quality welds and those which produce defective or cracked welds with wide variability in strength.

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* For aluminum spot-weld shear specimens of 0.040-in. thickness, the minimum average strength required by MIL-W-6858A is 435 lb. In Fig. 9, the mean tensile-shear strength of 0.040-in. thick aluminum welded ultrasonically is indicated as 900 lb or over, which well exceeds the requirements of MIL-W-6858A.

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QUALITY CONTROL IN
RESEARCH AND DEVELOPMENT

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To ensure the quality of engineering model equipment quality control should be in-
stituted during the research and development phases of a program. Minimum criteria for
conformance to MIL-Q-9858, "Quality Control System Requirements" are presented as well
as a suggested method of implementing the controls.

INTRODUCTION

During the past year, I have participated in the introduction of a formal program
of quality control in an electronics research and development (R&D) laboratory. During
this period many questions regarding the appropriateness of a formal quality control
program during R&D, and the proper means of implementing such a program have been con-
sidered. The material which follows represents the writer's opinion on a somewhat con-
troversial subject. It is hoped that the experiences presented will be of help to others
similarly employed.

HISTORICAL DEVELOPMENT OF QUALITY CONTROL IN R&D

New products are conceived, designed, fabricated, and refined during R&D. Until
approximately five years ago there was little "quality control" (in the sense that these
words connote for Manufacturing operations) during the process of research and develop-
ment of electronic products. Seldom were independent "quality control" agencies, apart
from those doing product design, functioning to assure specification compliance during
R&D. Many companies, with Quality Control Departments reporting at the same level as
Engineering and Manufacturing Departments, had some program for control of quality in
R&D stages. Other companies had Reliability Departments reporting to Engineering with
some responsibility for control of quality during R&D. However, with few exceptions, the
intensity of quality control efforts were much less during the R&D program phases than
during Manufacturing phases. Usually the practice was to have only enough quality con-
trol during R&D to prepare Manufacturing Quality Control personnel for the Manufacturing
phase of a program. Intensive quality control efforts were largely confined to Manufac-
turing. This situation has changed and is still changing in the electronics industry.

In recent years the functional capabilities of electronic products have greatly in-
creased. This increase has been accompanied by increases in equipment detail, limita-
tions on size and weight, constraints on development money, and compressions in time
schedules. Despite these factors product quality levels have had to be maintained and,
in many instances, improved.

In the past, it was possible to develop an experimental model, produce a set of draw-
ings and specifications during the course of equipment development, prove out these draw-
ings in R&D in the constructions of a prototype, and release a proven set of prints to
Manufacturing. Manufacturing would then produce quantities of equipments for field use.
The military customer would exercise control over the quality of this equipment by in-
specting and testing after product completion, prior to shipment to the field.

As products in Manufacturing became more complex, the military services realized
they could not expect to exercise control by repeating contractor inspections and tests
and began to specify minimum requirements for contractor quality control systems during
the Manufacturing phases of their contracts. The most well-known such specification was
the Air Force MIL-Q-5923, "Quality Control Requirements."

As the rate-of-change of the state of the art increased, products became obsolete
even during design. Expressed as a percentage, many more equipments in use in the field
were produced as experimental units than was previously the case. As a result, the ap-
propriateness of having quality control systems in effect during the course of construc-
ting these R&D equipments in order to assure specification compliance was recognized.
Not only this, but it was recognized that introducing quality control during the R&D
phase of a program would considerably reduce the time from design to full production by
contributing to the elimination of problems during the R&D phase that would have other-
wise gone to Manufacturing.

MIL-Q-9858, "QUALITY CONTROL SYSTEM REQUIREMENTS"

As a result of the above recognition, within the last two years, the Department of Defense has issued a coordinated quality control specification, MIL-Q-9858, "Quality Control System Requirements," as a replacement to MIL-Q-5923 (USAF) and also MIL-G-14461 (ORD).

Unlike MIL-Q-5923, this specification does not define one approach for Manufacturing and another for R&D. It would appear that it defines quality control system requirements for both R&D and Manufacturing, but, it makes no real distinction. However, there is more to having a specification accepted than its issuance and, at the present time, it does not seem to be uniformly accepted by industry and the military that MIL-Q-9858 pertains to R&D.

Also, since MIL-Q-9858 is considerably less detailed than MIL-Q-5923, there is much judgment which can be exercised by both industry and the military in its interpretation. The question can then be asked, "Does MIL-Q-9858 pertain to R&D, and, if so, how should it be interpreted?"

The conditions which apply for quality control in R&D are somewhat different from those which apply in Manufacturing. New "minimum criteria" for quality control in R&D need to be created which permit the flexibility required in an R&D environment.

RECOMMENDED MINIMUM CRITERIA FOR CONFORMANCE TO MIL-Q-9858

There are many interpretations which must be made regarding the applicability of MIL-Q-9858 to R&D. As mentioned above, it is just not appropriate to apply the same quality control measures traditionally applied to Manufacturing to R&D. Nevertheless, this does not mean that with a little bit of common sense and the application of some judiciously applied exceptions, it is not possible to live up to the spirit of MIL-Q-9858 in R&D.

The activities which follow are those where the traditional manufacturing approach to quality control, as typified by Phase B of MIL-Q-5923, may run head-on into the traditional flexible engineering approach of R&D. Ways of preventing an impasse are suggested.

Drawing and Change Control

One of the most difficult problems to solve when one tries to apply Manufacturing quality control procedures to R&D is the problem of controlling drawing changes. MIL-Q-9858, paragraph 3.3, Drawing and change control, states as follows: "A procedure shall be maintained to assure that the latest applicable drawing, technical requirement and contract change information will be available at the time and place of contractor inspection. Concurrently with the effectivity of revised drawings or changes, the contractor's change control shall assure that obsolete information is removed from all points of issue and use."

During R&D in many companies, drawings are not usually under a change control system and do not come under a change control system until released to Manufacturing. When an engineer has placed a part in the Model Shop for construction or has placed a part with a vendor for construction, he sometimes retains the master or tracing of the part. If trouble arises in the Model Shop, he may mark up and initial the print in the Model Shop. Similarly, when a purchased part is being made to an R&D drawing, the vendor will often call the Engineer when problems develop and the Engineer may empower the vendor to change the print and initial it in his behalf. If the changes are not incorporated into the tracing before Inspection's print is made the parts will be checked to the wrong print. If the Engineer neglects completely to change his tracing, there will be a lack of correspondence between delivered product and documentation at the time of shipment of the engineering model and an incorrect print will be released to Manufacturing.

These problems are, of course, not unique to R&D. They happen in Manufacturing as well. But, the fact that the prints are being used to construct parts or equipment for the first time results in a quantity of changes which is considerably above that in Manufacturing where prints are used which have already been upgraded through their use for the fabrication of Model Shop equipment.

One answer to the problem is: "Well, just stop such practices from going on. Forbid the use of marked-up prints, require that all changes to prints in the Model Shop be incorporated through formal change control procedures, and require that all instructions to the vendor be routed through Purchasing and that the vendor be instructed not to change

anything until he has it in writing from Purchasing." There seems to be universal agreement among Engineers that such a process would cripple an R&D program.

Some Engineering Departments think that permitting the Design Engineer to retain the tracings of his drawings during R&D and making him solely responsible for incorporating changes on tracings may result in a smoother operation, a better correspondence between delivered equipment and prints, and a better set of prints delivered to Manufacturing than if a system of change control were introduced. There is also feeling that the cost and time delays attendant with a formal program of change control would be prohibitive.

What is the answer to this dilemma? While the full rigors of a Manufacturing change control system are not appropriate to the R&D scene, nevertheless, some minimum change control system which puts some checks on the Design Engineer for change control is necessary. The following are the minimum criteria such a system should possess:

1. Any change which is not made directly to the tracing must be "marked up" on two "change prints", and a revision number assigned to these marked-up prints.
2. The effectivity date or model number of the change must be shown on the change prints.
3. The change prints must be dated and signed by some pre-designated responsible person.
4. One of these change prints must go to Quality Control.

In this fashion, Quality Control will have the latest applicable information to perform its inspection, and can check later to see that the latest information has been incorporated into the tracing at the time of release.

<u>Receiving Inspection</u>

Another problem which arises when one tries to apply Manufacturing quality control measures to R&D is how to control the quality of purchased material. MIL-Q-9858, paragraph 3.5.5 "Receiving Inspection" states, in part: "Subcontracted supplies shall be subjected to inspection after receipt, as necessary, to assure conformance to contract requirements. . . . . The contractor shall provide procedures for withholding from use all incoming supplies pending completion of required tests or receipt of necessary test reports, except that supplies may be released when under positive control. . . . ."

During R&D many companies do not require that purchased material be given a "receiving inspection" as required during Manufacturing. The reason given for this is that the Design Engineer is buying the material for his model and should have the prerogative of deciding whether or not it requires receiving inspection. Another reason given is that the Design Engineer will inspect and test the material himself and therefore receiving inspection constitutes a double inspection, the expense of which should be avoided. Still another reason given is that the parts being purchased for R&D are new parts which represent an advancement in the state of the art and that Receiving Inspection doesn't have the know-how or the equipment to check such parts. This is closely related to the concern that Receiving Inspection personnel may damage delicate items purchased for engineering models.

I believe that the Design Engineer should not have the prerogative of deciding what should or should not be inspected in Receiving Inspection when the item being purchased is intended for incorporation into a shippable model. The reasons for this opinion are that if purchased material is not examined in a routine fashion in Receiving Inspection, (a) the risk of having defective material in the delivered product is increased, (b) material detected as defective some time after receipt will not be as easily charged back to the vendor, (c) there will be no routine way to gather vendor quality history information "in order to initiate corrective action . . . . . as indicated by the nature and the frequency of the nonconformance" (MIL-Q-9858, paragraph 3.5.5). The latter is true since the feedback of defect information from Design Engineers to a central vendor data collecting agency will be sparse.

As to the position that the Design Engineer will inspect and test the material himself and that Receiving Inspection will constitute a duplication of effort; if Receiving Inspection checks the material, the Design Engineer's test will not be required, and Receiving Inspection can probably do it for less cost.

However, there is good justification for the position that, in some instances, Receiving Inspection will not possess the know-how or facilities to check certain parts or the cost of a suitable test jig may be disproportionate to the value of the test. The

solution for this situation is for Receiving Inspection to delegate to the Designer the
responsibility for the inspection of such an item of material and to provide him with
forms on which to document the results of his examinations. This way there will be some
assurance that the parts are actually inspected, and if the parts are defective, there
will be a routine generation of failure information for corrective action purposes.

The minimum criteria for Receiving Inspection in R&D are as follows:

1. All contract material should go through Receiving Inspection.
2. Material not intended for use in shippable equipment should be so marked, and
then inspected and tested in accordance with the instructions of the material requisi-
tioner.
3. Material intended for deliverable equipment shall be receiving inspected and
tested in accordance with specification requirements.

Measuring and Test Equipment

Yet another interesting area in the application of Quality Control measures to R&D
is the control of the accuracy of measuring and test equipment. A Design Engineer has
said to me, "First an engineer loves his wife, and next he loves his test equipment, and
I'm not sure this is always the order." Design Engineers are very sensitive about their
test equipment. They are proud of their test equipment, the way a craftsman is proud of
his tools. They will go to great lengths to accumulate the necessary test equipment
which will facilitate their work. They are not receptive to the idea that anyone else
will control their test equipment.

In response to a reminder of the importance of having test equipment in a proper
state of calibration before taking measurements for the establishment of specifications
or for the purposes of engineering model product acceptance, they may reply: "Any good
Design Engineer will make sure of the state of his test equipment before starting a test."
The implication is that since any good Design Engineer will make sure of the state of his
equipment before using it for the above purposes, and since all Design Engineers are
good, there is no need for a routine system of control.

There are some special considerations which must be made with regard to control of
maintenance and calibration of test equipment in R&D. In an R&D lab with an adequate
supply of test equipment, certain pieces of test equipment may not be in continuous use,
as they would be in Manufacturing, but may sit on the shelf until the time comes to make
a particular kind of measurement on a new project. It is not necessary to adhere to the
calibration schedule established for an item of test equipment when that item has not
been used from the time of one scheduled calibration date to the next. Provisions should
be made for this. If each item of test equipment were equipped with an "on-off" counter
or a running time meter, it would be possible to establish a calibration schedule based
on "times on" or "hours on" rather than elapsed calendar time periods. This might be the
best kind of schedule.

Another consideration is that certain items of test equipment may never be used for
the purpose of establishing equipment specifications, or for purposes of engineering
model product acceptance, but may only be used for trouble shooting, null indication, or
as a reference during tests. Where the use of such equipment can be controlled, these
factors should be considered in the establishment of the calibration schedule.

The minimum criteria for the control of maintenance and calibration of electrical
test equipment in an R&D laboratory should be:

1. All items of test equipment in use in the laboratory should be uniquely identi-
fied and recorded in a centralized file.
2. The calibration period for each item of test equipment should be recorded in the
file.
3. The calibration status of each item of equipment should be recorded in the file,
and on the equipment. That is, file and equipment should show dates of last and next
calibration.
4. Test equipment beyond calibration dates should be marked to that effect.
5. Specifications determined through the use of test equipment beyond calibration
date, or acceptance test results taken on such equipment should not be accepted.
6. Items of test equipment not in current use should be marked to that effect. At
the time it is desired to take them out of such "temporary storage," they should be cal-
ibrated and brought back into the system.
7. All new purchased items of test equipment should be inspected and tested on re-
ceipt, catalogued, and brought into the calibrations system.

8. Items of test equipment not used for measurement (that is items used for trouble shooting, null indication, or as a reference) should be marked to that effect and such use should be considered in the establishment of the calibration schedule.

The two big factors in all of the above are the competence of the calibration and repair personnel, and the schedules established for equipment calibration. It goes without saying that the calibration and maintenance personnel must be competent.

There are published schedules for the calibration of test equipment (one such schedule is as published in the Standards Laboratory Information Manual (SLIM) published by Bureau of Naval Weapons, Pomona, California). We must be careful not to waste money by checking equipment too often. Scheduled calibration periods should be based on having some small probability that an item of test equipment being calibrated will be out of calibration. Routine calibration should be scheduled so the probability of finding a piece of test equipment out of calibration is about five percent.

Product Inspection

Obviously, there must be a routine system of inspection for subassemblies, assemblies and units immediately after (and possibly during) their assembly in the Model Shop, and also a final inspection prior to shipment. One area of inspection which is sometimes overlooked in an R&D laboratory is the inspection which follows subsystem testing done by the Design Engineer. After a subassembly has been fabricated, it is turned over to a Design Engineer for tests. In the course of the Design Engineer's testing, modifications are made either by the Design Engineer or an engineering technician. In many instances, by intent, these modifications are not introduced in a workmanlike way. Resistors may be "tacked in"; leads may be "point-to-point"; long leads unsupported, etc. The reasons why modifications are introduced in an "unfinished manner" are valid. A lead being wired in, or a resistor being "tacked in" may very well be removed thereafter because the modification being tried does not accomplish its purpose, or because of some other modification made later. Since work is being done in this fashion, it is therefore necessary that an inspection be performed after such design testing to insure that final changes are properly installed.

Subcontractor Product Inspection and Test

One of the prime objectives in establishing a quality control system in R&D must be to keep from spending money foolishly. A very interesting consideration comes to our attention for this reason when we consider the inspecting and testing to be done by the contractor at the subcontractor. During the course of a subcontractor's designing, fabricating, inspecting, and testing a product for a contractor, contractor Design or Project Engineering personnel will have visited the subcontractor to give instructions, resolve problems, and observe progress. If then, Quality Control personnel desire to visit subcontractors to inspect equipment and observe tests, does this not represent a duplication of effort?

The answer to this question is, "It depends upon who the Design or Project engineers are, and who the Quality Control personnel are."

In an electronics R&D laboratory, some engineers get the reputation of being "good electrical men" and some get the reputation of being "good mechanical men." The happy combination of a "good electrical man" and a "good mechanical man" all-in-one is not always present. In the words of one Design Engineer, "it takes more than one lifetime to produce this combination." This is why it is possible for an electronics Design Engineer to visit a subcontractor periodically, discuss the progress of electrical design, and still have an equipment containing an excess of workmanship defects delivered by the subcontractor to the contractor.

There is no guarantee that sending a Quality Control representative to the subcontractor will preclude such an occurrence. What is important is that the proper mixture of electrical and mechanical backgrounds be blended in the Design, Project, and Quality Control personnel who visit vendors and subcontractors so that the subcontractors are not overwhelmed with contractor representatives and that all electrical and mechanical requirements for the equipment are met. This requires cooperation and common purpose between Project and Quality Control Supervision.

Subsystem Testing

What should be the role of Quality Control in the testing of engineering model subassemblies and units? Our response may be "Quality Control should test them all" if we

are quality control oriented, or "There is no need for Quality Control to test any of them" if we are not.

It might seem appropriate to those of us in Quality Control that a Design Engineer, starting with a set of equipment input and output parameters, could design an equipment to satisfy specification requirements, calculate all internal parameter nominals and tolerances, and turn the first model over to Quality Control for "acceptance testing." It just does'nt happen this way. The Design Engineer must test at least the first model. The testing which the Design Engineer does on the first model as he receives it from the Model Shop is part of the design process. From the Design Engineers view the approach must be, of necessity, empirical. For this reason, what is Quality Control to do while the Design Engineer is thus checking out such first subassemblies, assemblies, and units? Where Quality Control will have the opportunity to observe or perform Systems Tests on the first engineering model, Quality Control acceptance testing of the first models, sub-assemblies, assemblies, and units is not too much of a concern. Where there are param- eters specified by the system specification which cannot be observed at the systems level, but which must be observed at the subassembly, assembly, and unit level, it is appropriate that Quality Control personnel establish that the units meet such requirements.

As a program progresses subassemblies, assemblies, and units for the second, third, and possible fourth engineering models go to Design Engineers for test. The intent of such testing becomes less experimental in nature and more for purposes of proof of com- pliance. Quality Control can now assume a larger role and so relieve the Design Engi- neer of the onerous, repetitive features of this work.

Systems Testing

Systems testing on engineering models is usually done by Project or Systems Engi- neers. Once more the question of Quality Control's role in Systems Test, and the avoid- ance of unnecessary costs must be examined. If Systems or Project Engineers are going to determine that the engineering model conforms to all its specification requirements, why should Quality Control be concerned with systems tests. Doesn't this represent unneces- sary cost?

Systems tests can be considered to be made up of three phases, "debugging," proof of design," and "proof of satisfactory delivery condition."

In "debugging" tests various elements of the system are modified as necessary to the point where they are compatible. There will probably be little Quality Control interest in this phase of systems test.

In "proof of design" tests, Systems or Project personnel perform tests to determine that all specification requirements are satisfied. Depending upon the role of Quality Control in a given R&D laboratory, Quality Control may well have an interest in this phase of Systems test.

In "proof of satisfactory delivery condition" tests, it must be demonstrated that the equipment is in a fit state for shipment. Even though it may have been proved that the equipment design is capable of meeting specification requirements, this may have been accompanied by much modification and rework. This makes it appropriate to give the sys- tem a final abbreviated operability test, or a test which approximates that which the customer will perform when he receives the equipment. This last phase of Systems Test Quality Control will be most interested in.

Before giving my view of what the relative Systems Engineering/Quality Control Engi- neering relationship should be during R&D Systems Test, let us examine some of the moti- vations and viewpoints of the participants in Systems Test.

During the course of design, construction, and Systems Test, the Systems or Project Engineer has been a party to the resolution of various problems, and to the establishment of various systems compromises. In many instances, these may have been verbal agreements. He is motivated by a desire to see the system pass the tests and be shipped on schedule. How does this influence his performance of the Systems Test?

First, he is so intimately familiar with the system that he does not have to rely on the paper work which describes what the test requirements are and how the test is sup- posed to be conducted. He is not then aware that the course he is following is at vari- ance with the documented procedure as a result of all of the verbal agreements and ex- ceptions to which he has been a party. The result will be that when people later try to duplicate the test results following the written test procedure, they will not be able to

succeed. Second, there will be a natural tendency on the part of the Systems or Project Engineer to "pick a good day for the test," or to "tweak that extra pot" or to do something that will get the equipment over the hump when performance is marginal.

What then can Quality Control do? Quality Control can observe all the Systems Tests to make sure the test results are not being unduly influenced by a desire to meet shipment dates. Quality Control can run certain tests in accordance with the written test procedures in order to determine that the test procedures have been kept up to date. In a word, Quality Control can observe all tests, and <u>conduct</u> such other tests as it considers necessary to assure that the equipment meets <u>all</u> its performance requirements. One last interesting feature of the relationship of Systems, Project, and Quality Control Engineers during Systems Test involves trouble shooting which takes place in the event of failure.

On the first engineering model trouble shooting is probably best done by Systems and Project personnel. However, on subsequent models, it becomes appropriate for Quality Control personnel to participate in trouble shooting, and on the last Engineering models to do the trouble shooting entirely.

<p style="text-align:center">ESTABLISHING QUALITY CONTROL IN R&D</p>

Differences in Conditions which Apply for Quality Control in R&D

1. The ratio of people who can make policy in R&D to the total number of R&D personnel is larger than the ratio of people who make policy in Manufacturing to the total number of Manufacturing personnel. Another way of saying this is that in R&D a smaller percentage of people follow detailed and routine instructions than do so in Manufacturing.

The reason for this is that in an R&D laboratory where many projects are underway simultaneously, a major responsibility for planning, innovating, and implementing each project resides with the people assigned to that project and not with their supervisors. In a real sense, designers, project engineers, and specification writers are policy makers.

There are virtually many small companies under one roof, each of which plans, buys, fabricates, tests, and sells. The effect of this on the implementation of quality control is that in R&D a relatively larger number of people must understand and agree with the quality control objectives and program than must do so in Manufacturing. In an R&D laboratory, virtually everyone has to understand and agree. It is much easier to evade the quality control system in R&D. In Manufacturing on the other hand, there are relatively large numbers of people doing assembly and testing operations specified for them by fairly detailed instructions. These people do not have an equal opportunity or the inclination to evade the quality control system because the quality control system in Manufacturing has continuity and is very explicitly defined.

2. The problem of "status" regarding the responsibility for Quality Control is greater in R&D than it is in Manufacturing.

The practice in some R&D labs is to appoint a Project Engineer to a project at the initiation of design effort. He is responsible for gathering bids, assigning tasks, issuing funds, monitoring performance, meeting schedules, assuring <u>specification compliance</u>, and staying within budget. The Project Engineer "subcontracts" to various experts to design, fabricate, assemble, and test his product.

As an individual charged with overall project responsibility, there is a natural reason for the Project Engineer to believe it is his responsibility to establish the degree of quality control and the quality control standards on his project. In other words, there is a natural reason for the Project Engineer to believe Quality Control should be a service and not a control. The understanding which the Project Engineer has of the system requirements, and the first hand information which he has of what the customer wants, and what compromises the customer would be willing to make between cost, delivery, and quality, gives the Project Engineer a natural reason for feeling his judgments should prevail in matters regarding quality control.

This condition will present some difficulties if the requirements for Quality Control organizational independence, as specified in MIL-Q-9858, are not properly implemented.

3. The organizational relationships between customer, company (other than Quality

Control) and Quality Control are more complicated in R&D than in Manufacturing.

There is an interesting set of relationships which develop between company Quality Control, Project Engineering, Design Eengineering, and Contracts, and customer Project Engineer, Contracts Officer, and Resident Military Inspector.

There is usually a very good relationship between the customer Project Engineer and the company Project Engineer. Both usually have similar backgrounds and understand one another. The customer Project Engineer reports to a military R&D procurement branch and the company Project Engineer is part of the company's Engineering Department.

As a program progresses, these individuals work together facing many problems and making decisions when they arise. When questions of marginal quality arise where either the schedule must slip, costs rise, or the specification requirements be relaxed, there is a natural tendency for the customer Project Engineer and the company Project Engineer to work out a "gentlemen's agreement" regarding future corrective action without going through the process of requesting a waiver to the specification through the company's Contract Administrator. A reason for this is that requesting a waiver takes time and may affect schedules, and some customer and company Project Engineers feel that the requesting of a waiver reflects unfavorably on their performance.

The advantage of such a course of action to a company's Engineering Department is that it can build up good will with the customer's Engineering Representative which is favorable to sales and general working relationships. The disadvantage to both parties is that either (or both) Project Engineers may leave the project and any "gentlemen's agreements" previously made, may be repudiated by his successor.

The company Quality Control specialist's position is simple in this situation; "Make it like the specification or get a waiver." The Resident Military Quality Control specialist's position is the same. There is a temptation at this point for the contractor and customer Quality Control representatives to team up in order to have the "gentlemen's agreement" aforementioned formalized. However, the Resident Military Quality Control Representative reports to some military Manufacturing branch and, in question of doubt, takes his lead from the military R&D Contracts Officer on the project. He may not therefore be in a position to insist that this be done. If the problem goes unresolved into Manufacturing, the contract then being under the cognizance of a military Manufacturing procurement branch, the Resident Quality Control Representative may repudiate any "gentlemen's agreements" made earlier in the program by the customer and company Project Engineers. The customer and contractor Project Engineers might take the attitude that they are not unduly concerned about the possibility of this at the time they make their agreement since, when and if this happens, they will probably no longer be associated with the project anyway.

The above conditions tend to make allegiances develop which are associated with an individual's field of endeavor and not his company agency affiliation. This is wrong.

<u>RECOMMENDED APPROACHES</u>

<u>Developing the Quality Control Program Plan</u>

Because a development laboratory is a location where many projects can be underway simultaneously, each at a separate stage of completion, and because each such project is essentially under its own management, it is very important that those managing such projects be aware of the objectives, plans, responsibilities and authorities of Quality Control.

For this reason, it is most appropriate that a Quality Control Program Plan be prepared which describes the objectives, approach, organization, responsibilities, and authorities of Quality Control. It is recommended that prior to the finalization of this plan it be circulated to key individuals for comment, criticism, and suggested improvements.

In this regard, it is important to note that within the environment of an R&D laboratory there will be certain people who are looked upon as leaders because of their technical excellence, experience, or length of service with the company. The influence which such leaders exert may be out of proportion with that indicated by their position on the organization chart. It is most important that every effort be made to gain the support of such leaders and to tailor the Quality Control program so that its objectives and those of such individuals correspond.

It goes without saying that the manager of the R&D laboratory must support and endorse the Quality Control program. In general it will be found that once Design Project Engineers, or those who provide engineering services understand the Quality Control program that has been agreed upon, they will cooperate. When they understand the procedures to be followed, the activities to be engaged, in the standards to be followed, and can utilize such knowledge in their planning, they will do so. They will not appreciate rejections based on standards not in existence when products were being designed, or admonitions for not following procedures that were not in existence when they were establishing their schedule and their budgets.

For this reason, it is recommended that in an R&D laboratory, Quality Control be initiated on a project-by-project basis, beginning on each project at the bid stage. In this fashion, there will be agreement between Project and Quality Control personnel on the entire Quality Control program to be followed.

ESTABLISHING QUALITY CONTROL PROCEDURES

Following the promulgation of the Quality Control Program Plan, the broad objections outlined in that document must of course be detailed in specific Quality Control procedures, and the Quality Control standards to be employed must be promulgated.

There are two approaches to the preparation of such procedures and standards. One approach is to prepare such material unilaterally and disseminate it to the laboratory as the final authority. Another approach is to distribute such procedures and standards prior to issuance for criticism and comment, and to work toward common acceptance before finalization. The latter approach will be more time consuming but will lead to much more lasting results.

Where an R&D Laboratory has a Procedures group, it is recommended that the services of this group be utilized to coordinate the finalization of Quality Control procedures which affect the activities of other groups. It is also recommended that such Quality Control procedures be included in the Laboratory's Operations Manual rather than in a separate Quality Control Manual. In this fashion, the Quality Control procedures which relate to the R&D laboratory are under the aegis of the Engineering Lab Manager and there is no question about the relevance of such procedures to the Design and Project Engineers.

The Quality Control Department

In parallel with the formulation of plans and procedures, the Quality Control Department must be staffed.

In an electronics R&D laboratory, the primary skill which is required for a Quality Control Engineer is competence in electronics. It would be helpful if he had a working acquaintance with statistics, and enough knowledge of mechanical engineering and shop practices to know where to go to get answers. The Quality Control Engineer must be able to recognize good and bad workmanship in all of the forms it takes in electronics equipment. Personality requirements are equally severe and individuals of the type described above must be developed from personnel selected for potential capabilities in the required areas. A possible approach to organizing an R&D Quality Control Department is as follows:

A Project Quality Control Engineer can be assigned (on a part time basis for small projects) from the Quality Control Department to each job. This individual can be given the responsibility to plan an effective Quality Control program on his project. This would include preparing test procedures for parts, units, and systems under various environmental conditions, participating in the disposition of rejected material, and in all other ways, acting as "Quality Control Manager" on that job.

This individual can have the Quality Control services of inspectors, testers, test equipment maintenance and calibration personnel, and environmental-testing personnel made available to him.

Through the assignment of the Quality Control responsibility, the Project Quality Control Engineer will, in a sense, become part of the project team and become a valuable aid to the Project Engineer.

It is most important that the proper attitude exist between the Project Quality Control Engineer and the Project Engineer. The Project Quality Control Engineer can be of great help to the Project Engineer in meeting the objective of shipping, on time, equipment which complies with specifications. The Project Engineer can be of great assistance

to the Project Quality Control Engineer in supporting his activities and his decisions.

As was mentioned above, the consideration of who is responsible for quality in an R&D laboratory is just as important as the consideration of who is responsible for quality in Manufacturing.

In an R&D laboratory, the Project Engineer is given the responsibility for designing a new product and having a model fabricated and tested. He is responsible for the shipment of a product which conforms with specification requirements in accordance with a schedule. He must stay within a budget. He is given the authority to buy services, control expenditures, and deal with the customer. When in the implementation of a Quality Control program in R&D, someone other than the Project Engineer is given, or assumes, some responsibility for quality a natural response of a Project Engineer might be that the Management is taking away part of his authority; therefore, he may conclude he can no longer be held completely accountable to control budgets, schedules, and specification compliance.

To a certain extent, this is true; however, the response of one Manager of Engineering to this contention is interesting. To the above he replied, "I have always had the ultimate responsibility for the quality of the equipment shipped from this laboratory. I am not taking away the responsibility of the Project Engineer for qualtiy. I am delegating to Quality Control part of the authority for control of quality I have always had."

Regardless of who is responsible, the fact remains that where the Project Engineer and the Project Quality Control Engineer have a common desire to work together for the mutual interest of the company, with good faith and mutual respect and understanding, they can both help one another considerably.

CONTROLLING QUALITY IN THE PRODUCTION-ENGINEERING CLIMATE *

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Frankford Arsenal

Introduction

The control of product and process quality in the production-engineering climate where new and modified weapons, ammunition, and fire control instruments are manufactured in diversified quantities and types is a real challenge. This challenge is surrounded by quality problems where the solutions do not necessarily commence with a rigid search for answers as much as it begins with the flexibility of your perceptions. The real task, and it is generally a tailor-made one, is to place the problem in the right perspective and to measure it against the conditions of the actual industrial situation in which it originated. Thus, in this situation, with independence of movement and direction, quality control can objectively approach the wide variety of daily quality problems indigenous to the production-engineering climate and provide rational conclusions. The objective approach, however, must possess an organized method of attack. A systematic procedure to controlling quality is a requisite.

Purpose

It is the intent of this paper to describe the methods and techniques employed at the U. S. Army Ordnance installation, the Frankford Arsenal, in "Controlling Quality In The Production-Engineering Climate." Frankford Arsenal has a manufacturing capability for production of development type items and limited, initial production runs. This is a means whereby the necessary production engineering is performed during the phase of the development of an ordnance item and the phase where private industry undertakes quantity production using product engineering drawings and specifications which delineate the desired requirements.

Background

Before entering into this discussion, however, it could prove advisable to the reader if a brief description   was presented as to the Frankford Arsenal mission in light of today's industry--government teamwork. This can serve as a denominator over which the direction and activities of quality control can be measured or evaluated.

The Frankford Arsenal today is primarily a research and engineering center with responsibility to the nation for developing and engineering for mass production, new weapons, ammunition, materials, and methods. Frankford Arsenal shops are recognized authorities in the United States for optical, electronic, mechanical, hydraulic, and propellants production engineering. The optical shops produce optical ranging, sighting, and observation equipment, and afford assembly facilities for pilot and production runs of complex optical instruments. The electronic shops have facilities for developing and producing pilot lots of printed circuits, microminiaturized components, and potted parts for computing, fire control and integrated weapon systems. Complete facilities for producing pilot runs of ammunition ranging from cal. .30 rounds to 155mm shells, and mechanical time fuzes are maintained in the ammunition and fuze shops respectively. These, together with a variety of auxiliary shops, are capable of producing complete, integrated guidance and control portions of weapon and missile systems, small arms and major caliber ammunition, metal components, and propellants. These shops are equipped with fine multi-purpose tools, the most modern equipment, special and automatic tools only required to develop and test out important new manufacturing techniques, and manned by highly trained career workmen, technicians, and scientists.

In the case of this presentation, the Frankford Arsenal shops are under the Manu-
facturing Branch which is part of the Operations Division. The Operations Division
also consists of a Process Inspection Office, Production Engineering Branch (the
Quality Control Section is a segment of this branch) and Program Management Branch.
The Manufacturing Branch is made up of approximately 1400 skilled machinists, tool-
makers, gage makers, and machine operators assigned throughout 30 shop buildings.

Discussion

In this discussion, an attempt will be made to explain the responsibilities and
techniques associated with the Quality Control Section during the various stages of
product growth. Quality Control, as described in this paper, is a manufacturing sup-
port activity, concerned with detection, verification, correction, and prevention
aimed at establishing and maintaining optimum levels of product and process quality.

The details of the quality control function in the Operations Division include:

1. Plan, direct and coordinate quality control activities throughout the entire
    Operations Division (includes Manufacturing, Process Inspection, Program
    Management, and Production Engineering).

2. Develop and verify quality control standards, plans, and procedures for div-
    ision-wide application.

3. Continuously analyze, evaluate and report product and process quality and
    cost of achieving and maintaining this quality.

4. Investigate, analyze and correct product and process quality problems, and
    initiate control measures to prevent reoccurrence, recommending corrective
    action.

5. Perform research and development in sampling plans, quality control and reli-
    ability techniques and methods.

6. Provide training in quality control.

7. Delineate quality control requirements to suppliers.

8. Feed back product and process quality data for utilization in design and
    production.

9. Investigate and develop new methodology in inspecting and measuring.

10. Provide technical guidance and assistance in the field of quality control.

It has been found that a three-stage approach to controlling product and process
quality is most effective for our production-engineered jobs. These stages are consid-
ered as:

> STAGE   I - PRE-PRODUCTION
> STAGE II - INITIAL PRODUCTION
> STAGE III - PROCESS STABILIZING AND REGULAR PRODUCTION

Inherent in each of these stages are the various quality control techniques that will
be described. Figure 1 depicts these techniques. It should be mentioned that while
the techniques have been tailor-made to fill the quality control needs at this instal-
lation, it is felt that they are general enough to be possibly considered for other
types of production-engineering activities.

STAGE I - PRE-PRODUCTION

Preproduction represents that stage in the manufacturing cycle preceding the
actual manufacturing, where the procurement, methodizing and planning are performed.

QUALITY CONTROL ACTIVITY DURING THE MANUFACTURING CYCLE

JOB ASSIGNED TO OPERATIONS DIVISION

STAGE 1 (PRE-PRODUCTION)

| PRODUCT & PROCESS QUALITY REPORTING METHOD | DEVELOP DETAIL INSPECTION PLANS FOR PROCESS INSPECTION | INITIATE QUALITY ALERTING PROCEDURE TO STUDY PAST MORTALITY & QUALITY PROBLEMS | DEVELOP APPLICABLE SAMPLING PLANS FOR PROCESS INSPECTION | INVESTIGATE NEW & REFINED GAGING DEVICES | DELINEATE TO SUPPLIERS THE QUALITY REQUIREMENTS OF PURCHASED MATERIAL | STUDY DRAWINGS, SPECS, REQUIREMENTS FOR POTENTIAL QUALITY TROUBLE SPOTS, DESIGN DEFICIENCIES, ETC. |

STAGE 2 (INITIAL PRODUCTION RUN)

| ATTRIBUTE CONTROL CHARTS ("P" & "C") PER PRODUCT & SHOP | PROCESS CAPABILITY STUDIES ON LEADING DEFECTS & POTENTIAL TROUBLE SPOTS | ISSUE QUALITY CONTROL INSTRUCTIONS TO PROCESS INSPECTION | AUDIT PRODUCT & PROCESS QUALITY RESULTS & INITIATE CORRECTIVE ACTION | TRAINING & ORIENTATION IN QUALITY CONTROL TECHNIQUES | DEVELOP NEW TECHNIQUES FOR ANALYSIS OF QUALITY PROBLEMS | COORDINATE QUALITY CONTROL & PROCESS INSPECTION QUALITY EFFORT |

STAGE 3 (PROCESS STABILIZING & REGULAR PRODUCTION)

| PERFORM STATISTICAL STUDIES ON QUALITY PROBLEMS & OVERALL PROJECTS | ISSUE QUALITY CONTROL INSTRUCTIONS TO PROCESS INSPECTION | REVIEW & ADJUST INSPECTION SAMPLING PLANS WITH NEED | VARIABLE CONTROL CHARTS (XBAR) ON LEADING DEFECTS & POTENTIAL TROUBLE SPOTS | AUDIT PRODUCT & PROCESS QUALITY RESULTS & INITIATE CORRECTIVE ACTION | ANALYZE QUALITY PROBLEMS FOR FEEDBACK TO ENGINEERING & MANUFACTURING | ANALYZE COSTS OF ACHIEVING & MAINTAINING PRODUCT & PROCESS QUALITY TARGETS |

| COMPREHENSIVE MANAGEMENT TYPE REPORT OF PRODUCT & PROCESS QUALITY |

Fig. 1

QUALITY ASSURANCE — INSPECTION DETAIL PLAN

Fig. 2

NOMENCLATURE SABOT   DWG. No. D-867297   WORK ORDER 91065   DATE 5-1-60

END ITEM 105 MM M409   REVISION A-5-2-60   PLANNED BY RLK   SHEET 1 OF 2 S

OPER. No.	CHARACTERISTICS TO BE INSPECTED	SHOP	1st PIECE	MACHINE INSP.	LOT Major	LOT Minor	100%	GAGE OR FIXTURE	NOTES
5	3.002 +.009 DIA	9511	X	3rd NOTES	.25			INDICATOR B-8658471	CONTINUOUS SAMPLING PLAN (CSP#1) Q=190 f=.1
5	2.9100 +.0098 DIA	"	X	"	.25			INDICATOR B-865712	CSP#1 Q=190 f=1/10
5	2.888 +.002 DIA	"	X	"		.40		AMPLIFIER A-754 STD EYE PLUG RING SETTING A-8663B47	CSP#1 Q=40 f=1/10
10	3.900 -.005 DIA	"		"		1.0		SNAP DIAL B-865842C	CSP#1 Q=80 f=1/10
10	3.9000 -.014 DIA	"	X	"	.25			SNAP DIAL B-869 5173	CSP#1 Q=190 f=1/10
10	.24 +.02 LENGTH	"		"		1.0		LENGTH GAGE A-8529172	CSP#1 Q=80 f=1/10
10	ROCKWELL "B" 95 MIN	"		"		.40		ROCKWELL TESTOR 13-952-3712	VARIABLE SAMPLING RANGE METHOD (MIL 414)
15	.05 DEEP RECESS	"	X	"		.40		FLUSH PIN C-864 5129	CSP#1 Q=140 f=1/10
15	1.40 MAX	"	X	"		1.0		LENGTH GAGE A-8645125	CSP#1 Q=80 f=1/10
20	.5164-.0190 WALL THICK.	"	X	"	.25			INDICATOR-SET CHECK B-864 5137	CSP#1 Q=190 f=1/10
20	.001 CONC. @ 2.888 ID WITH OD	"	X	"			X	FIXTURE D-864 5123	CRITICAL CHAR.
20	7.500-.005 LENGTH	"	X	"		1.0		SNAP GAGE C-864 5123	CSP#1 Q=80 f=1/10
25	SLOTS-MISSING/CORRECT	"	X	"	.25			VISUAL	CSP#1 Q=190 f=1/10
30	BURRS	"		"		.40		VISUAL	CSP#1 Q=140 f=1/10
35	CHROME PICKLE FINISH MIL-STD-171, TYPE I	9512		"		.40		VISUAL	SIMPLE SAMPLING BY ATTRIBUTES (LOT)
	SALT SPRAY	9520		"				REFER TO INSPECTION SALT SPRAY TESTING	SIMPLE SAMPLING BY MIL MORE QCP-5-60

QUALITY ALERT NOTICE   SHEET 1 OF 1

TO: METHODS ENGR. & MACHINE SHOPS 1 & 2	DATE: 7|2|59	ALERT NUMBER: QA 65-59
FROM: QUALITY CONTROL SECTION	WORK ORDER NUMBER:	DRAWING NUMBER: C-7527307
NOMENCLATURE: HOUSING	END ITEM: MT. TELESCOPE M-92	

PREVIOUS QUALITY FAILINGS				SIGNIFICANT DEFECTS	
DATE	WORK ORDER NUMBER	QUANTITY INSPECTED	QUANTITY DEFECTIVE	REQUIREMENT	PAST INSPECTION FINDINGS
8-17-56	69273	110	15	1.750 +.005	1.750 to 1.770
				3.9215 +.0005	3.9216 to 3.9225
1/5/57	72593	200	24	1.750 +.005	1.752 to 1.764
6/10/59	85290	27	12	3.9215 +.0005	3.9216 to 3.9223
12/1/60	96570	55	7	63 rms finish	60 rms to 100 rms
2/7/61	97810	35	10	63 rms finish	60 rms to 80 rms

REMARKS:

Drill Bushing replaced on 3.9215 +.0005 dimension
More frequent check of surface finish (63 rms) required

Fig. 3

It is in this stage where quality control is concerned with the development of inspection plans for process inspection, the review of past mortality on like or similar parts, the development of new or modified sampling plans, the investigation of new or refined gaging and/or control devices, the development of quality control requirements for procured material, and the review of drawings and specifications for design, product, or process deficiencies, as well as quality control needs in subsequent stages of product growth. Details of these factors are explained below.

1. Development of Detail Inspection Plans for Inspection

Detail Inspection Plans are developed to assure standardization and proper degree of inspection during processing and assembly. Included in such plans are the characteristics to be checked, classification of such characteristics, acceptable quality levels, types of measuring equipment and special instructions to inspectors. Inspection and manufacturing personnel normally receive these plans prior to Stage II, when the job commences in manufacture. Where the job is of a small quantity (1-25 pieces) and of short duration (less than a few months), minimum effort is directed towards the development of such inspection plans. An example of the Inspection Detail Plan is presented in Figure 2.

2. Quality Alerting Procedure

Inherent in any job shop is the processing of jobs (components or assemblies) that possess some degree of similarity to jobs that have been previously produced. The Quality Alerting Procedure is a technique that includes the review of past quality performance of similar jobs. As a result of this review, past repetitive quality problems or trends are highlighted for the attention of methods engineering, manufacturing, or process inspection. The "Quality Alert Report" can accompany the job through all stages of manufacture, alerting manufacturing and inspection supervisors, machinists, operators and inspectors as to past problems on the job or a similar one. The value of the Quality Alerting Procedure is that while the time interval between like or similar jobs can be a few years, past objective evidence is excellent reference information. While our memories can play havoc with us in the production-engineering climate due to the wide variety of jobs being handled concurrently, objective evidence fills the need. Figure 3 is an example of the "Quality Alert Report."

3. Development of Sampling Plans

Statistics is the science of working with data noticeably influenced by chance causes. Whether we have data from mass production or from short runs, as long as we have some degree of repetitiveness during the production cycle, sampling developed by statistical methods can be applied. (In 1920, the development of the theory of small samples permitted the departure from the need of masses of data). As most quality control people know the basis for the statistical quality control approach is the concept of alikeness, rather than quantity. Alikeness implies that whether you produce 25 pieces or 2500 pieces, the amount that one part differs from the preceding one is not significant. In general, tailor-made sampling plans, with their risks and limitations understood, can be applied to determine the degree of alikeness. As a matter of fact, due to the heterogeneous variety and quantity of work flow under job lot conditions at this installation, tailor-made sampling plans are the routine rather than the exception. Variations of attribute (single, double, multiple, and continuous) and variable sampling are thus employed.

The AQL (acceptable quality level), AOQL (average outgoing quality limit), and LTPD (lot tolerance percent defective) bench marks are considered when constructing sampling plans. Our approach to the application of sampling plans is that it should guarantee customer requirements, it should be easy to understand and apply, it should be statistically sound, and it should be surveilled when in operation. An example of a specialized attribute sampling plan for small lot sizes is illustrated in Figure 4. A further example which depicts characteristics classified and their associated AQL's is shown in Figure 4a. In figure 4b is an example of a Multi-Level Continuous Attribute Sampling Plan.

SINGLE SAMPLING TABLES FOR SMALL LOTS
(I TO 200 PCS.) AND A.Q.L.'s LESS THAN 0.65%

LOT SIZE	MAJOR			MINOR		
	SAMPLE SIZE	ACC.	REJ.	SAMPLE SIZE	ACC.	REJ.
1-25	100%			100%		
26-45	25	0	I	15	0	I
46-60	30	0	I	15	0	I
61-75	30	0	I	15	0	I
76-110	30	0	I	15	0	I
111-200	40	0	I	15	0	I

NOTES:

    I. MAJOR CHARACTERISTIC

        A MAJOR CHARACTERISTIC IS A CHARACTERISTIC WHICH IS A REQUIREMENT ON THE FINISHED PRODUCT, A CHARACTERISTIC WHICH COULD PREVENT THE COMPONENT OR ASSEMBLY FROM MEETING THE FINISHED PRODUCT REQUIREMENT AFTER PROCESSING OR A CHARACTERISTIC WHICH COULD AFFECT THE ASSEMBLY OF THE END PRODUCT, OR CAUSE FAILURE TO FUNCTION IN ACCORDANCE WITH THE INTENT OF THE DESIGN.

    2. MINOR CHARACTERISTIC

        A MINOR CHARACTERISTIC IS A CHARACTERISTIC WHICH WHEN DEFECTIVE, DOES NOT MATERIALLY REDUCE THE USABILITY OF THE UNIT OF PRODUCT FOR ITS INTENDED PURPOSE. SUCH CHARACTERISTICS ARE RADII, CHAMFERS, CLEARANCES, FRACTIONAL TOLERANCES OR EQUIVALENT, WORKMANSHIP, PIECE MARKING, AND ROUGHING OPERATIONS.

Fig. 4

CLASSIFICATION OF DEFECTS AND AQL'S TO BE USED IN PROCESS INSPECTION
for
VARIOUS TYPES OF OPTICAL ELEMENTS AND SUB-ASSEMBLIES

LENSES

MAJOR
1 Diameter
2 Axial Thickness
3 Optical Requirement
  Equiv Focal Length
  Back Focal Length
  Concentricity
  Definition
4 Cement
5 Surface Quality
  (Up to 20-10)

MINOR
41 Surface Quality
  (above 20-10)
42 Coating Hardness
43 Coating Hardness
44 Edge Thickness
45 Chamfer
46 Limit Edge Defects
47 Presence of Part No
48 Blackening of Rim
49 Workmanship

RETICLES

MAJOR
1 Diameter
2 Accuracy of Pattern
3 Displacement of Pattern
4 Surface Qual Inner Zone
  (Up to 20-10)
5 Thickness of Etched Lines

MINOR
41 Deviation
42 Surface Qual Outer Zone
  (above 20-10)
43 Chamfer
44 Thickness
45 Presence of Part No
46 Rim Ground or Polished
47 All Other Etch Data
48 Workmanship

PRISMS, MIRRORS, WEDGES

MAJOR
1 Light Dev Pyr Error and
  Perpendicular to base
2 Sph Power, Light Path,
  Resol and Astig
3 Reflect and Light Trans
4 Cement and/or Strength
  of Bond
5 All Linear Dim with Tol
  range up to .010" and
  Angular Tol range up
  to 10 min

MINOR
41 Volume
42 Surface Quality
43 Coating and/or Alum Qual
44 Coat Hardness and/or
  Alum Adherence
45 Protective Backing
46 Presence of Blackening
47 Presence of Part No
48 All Linear Dim with Tol
  Range above .010" & Ang
  Tol range above 10 min
49 Workmanship

WINDOWS, FILTERS

MAJOR
1 Diameter
2 Resol, Sph Power, and
  Astig
3 Light Deviation
4 Reflect and Light Trans

MINOR
41 Thickness
42 Surface Quality
43 Coating Quality
44 Coating Hardness
45 Limit Edge Defects
46 Chamfer
47 Rim Ground, Polished
  or Blackened
48 Presence of Part No
49 Workmanship

OPTICAL SUB-ASSEMBLIES

MAJOR
1 Completeness of Assy
2 Presence of Sealing Comp
3 Dim Governing Fit with
  Mating Part
4 Optical Requirements

MINOR
41 Finish
42 Coordination of Optics
43 Cleanliness
44 Coating
45 Workmanship

TYPE OF ELEMENT	GRIND **		POLISH **		CENTER		COAT		CEMENT		ETCH		ASSEMBLY	
	MAJOR	MINOR	MAJOR	MINOR	MAJOR	MINOR	MAJOR	MINOR	MAJOR	MINOR	MAJOR	MINOR	MAJOR	MINOR
Lenses	6.5%	6.5%	2.5%	4.0%	1.5%	4.0%	1.0%	2.5%	0.65%	2.5%				
Reticles	1.5%	4.0%	1.0%	4.0%							0.65%	2.5%		
Prisms, Mirrors, Wedges	1.0%	4.0 12.5% [a]	1.0%	4.0%			1.0 .065% [b]	2.5%	0.65%	2.5%				
Windows, Filters	1.0%	4.0 12.5% [a]	1.0%	2.5%			0.65%	2.5%						
Optical Sub-assemblies													0.65%	2.5%

AQL in percentages to be used   a. for "Same Surface Quality" Material;
     b. if Shop indicated is last processing area

** = Elements processed thru both Grind and Polish Shops will be inspected after Polish
     for characteristics generated in grinding and polishing operations

Fig. 4a

FLOW PROCESS CHART FOR MULTI-LEVEL
CONTINUOUS SAMPLING PLANS

Fig. 4 b

4. Investigation of New and Refined Gaging and Measuring Devices

The production-engineering of diversified quantities of complex and less complex items necessitates the need for a flexible gaging measuring program. Coupled with this, from the quality control viewpoint is the search for adaptations of such gaging and measuring equipment to semi-automated and automated systems for highly efficient process control. Quality Control is not concerned with specifying and ordering gages and measuring equipment--this is the job of process inspection. Quality Control is, however, most concerned with advancing the application of new or refined gages and measuring equipment to realize increased inspection productivity, repeatability of readings, greater accuracy on tolerances of the magnitude of .00005 inches, and means for rapid control of process quality whereby machines or operators can control and guide their process before spoilage is realized. For example, investigation can be undertaken in an effort to adapt pneumatic or electronic gaging equipment to computers so that the capability of processes can be rapidly determined. An extension of this idea in variable control charting is where the subgroup individual measurements are fed directly into computers together with control limits. The rapid answer indicates whether to continue to run the process, adjust process, or stop process. Another example of this type of investigation can be the attempt to automatically perform visual inspection on brass ammunition cases on a continuous basis. An electro-mechanical device with an automatic loading and feeding device can be considered for evaluating surface nicks, dents, etc., with the findings fed into a computer which automatically calculates the total fraction defective rate and fraction defective for Major and Minor defects.

Then again, consideration might be given toward a gaging device which will standardize upon optical inspection, to eliminate the possible wide influence of human judgment. The light source, positioning of the elements, viewing, and comparison with standards would be made uniform for all elements.

There is a very positive need in quality control, early in the life of the product, to consider newer and better ways of gaging and measuring.

5. Quality Requirements for Suppliers

Difficulties by suppliers in producing satisfactory Ordnance quality can be related many times to inadequacies in supplier's quality control, competitive forces, and lack of understanding on the part of the supplier and the Ordnance as to what constitutes satisfactory product quality requirements. These problem areas create the important need for Ordnance to better analyze its product requirements and develop more meaningful specifications, to provide suppliers with realistic quality assurance provisions, to maintain real cooperative relations with suppliers, and to evaluate the supplier's product and process quality more accurately and objectively.

Thus, in helping the supplier to effectively distribute his control efforts in accordance with Frankford Arsenal product quality requirements, we are now delineating to our suppliers, at the time the bids are asked for, general and detailed quality assurance provisions. General provisions (Figure 5) include such features as Supplier (Contractor) Inspection System, Verification of Supplier (Contractor) Inspection System, Tolerances, Workmanship, Finishes, etc., while detailed provisions (Figure 6) spell out the AQL's (acceptable quality levels), CC's (classification of characteristics), and sampling plans. We feel that good communications between Frankford Arsenal and its suppliers (contractors) is the key to good customer relations, avoiding trouble, and getting out of trouble as soon as possible. With effective communication of product quality requirements, suppliers will know what is expected of them quality-wise, possess a good idea of quality control techniques desired by the Frankford Arsenal, be assured of consistent practices between supplier inspection and Frankford Arsenal inspection surveillance, and effectively provide sound, objective evidence for Frankford Arsenal evaluation in product acceptance.

A. Product Quality Requirements

A-1 Insulation Resistance, with all switches closed. The insulation resistance between the following terminals: 1 & 2, 1 & 3, 1 & 4, 2 & 3, 2 & 4 and 3 & 4 shall be 100 megohms minimum, when measured at 500 $\neq$ 10 volts, DC.

A-2 Circuit Resistance. The circuit resistance of the 3 switches and all combinations of 2 of the 3 switches through each closed circuit shall not exceed 0.2 ohms maximum under the following conditions: open circuit voltage 5.5 $\neq$ 0.5 volts, DC; current 100 $\neq$ 2 milliamperes (Switches 1 and 2 closed, 1 and 3 closed, and 2 and 3 closed. Circuits: 1-8, 2-7, 3-5 and 4-6).

A-3 Jolt. The switch and cable assembly shall withstand the jolt when tested in accordance with Mil-Std-350 when assembled in a test vehicle similar to the Arm Safe Device. There shall be no completed circuit or closed switches upon completion of the test.

A-4 Jumble. The switch and cable assembly shall withstand the jumble when tested in accordance with Mil-Std-351. The assembly should jumble in a container when assembled in a test vehicle similar to the Arm Safe Device. There shall be no completed circuit or closed switches upon completion of the test.

A-5 Forty (40') Foot Drop. The switch and cable assembly shall withstand the drop when tested in accordance with Mil-Std-352 when assembled in a test vehicle similar to the Arm Safe Device. There shall be no completed circuit or closed switches upon completion of the test.

A-6 Five (5) Foot Drop. The switch and cable assembly shall withstand the drop when tested in accordance with Mil-Std-358, when assembled in a test vehicle similar to theArm Safe Device. There shall be no completed circuit or closed switches upon completion of the test. The assembly shall be operable after this test.

A-7 Vibration. The switch and cable assembly shall withstand the vibration when tested in accordance with Specification Mil-E-005272A, Procedure XI. After vibration the assembly shall be operable.

A-8 Low Temperature. The switch and cable assembly shall withstand the low temperature (-40°F) when tested in accordance with Specification Mil-E-005272C, Procedure I. The assembly shall be operable at this low temperature.

A-9 High Temperature. The switch and cable assembly shall withstand the high temperature ($\neq$125°F) when tested in accordance with Specification Mil-E-005272C, Procedure II. The assembly shall be operable at this high temperature.

A-10 Temperature Shock. The switch and cable assembly shall withstand temperature shocks when tested in accordance with Specification Mil-E-005272C, Procedure I. Upon completion of temperature conditioning, the assembly shall be operable.

B. Quality Assurance Provisions

B-1 Contractor Inspection. Unless otherwise specified, the contractor or supplier shall be responsible for the performance of all inspection requirements prior to submission for Government inspection and acceptance. Except as otherwise specified, the contractor or supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. Inspection records of the examinations and tests shall be kept complete and available to the Government.

B-2 Government Verification for Contractor Inspection.

   a. All inspection operations performed by the contractor or supplier and all material supplied by the contractor or supplier will be subject to Government verification. Verification will consist of: (1) Government sampling to measure quality of product, (2) check of the contractor's or supplier's inspection operations, and/or (3) periodic analysis of the contractor's or supplier's inspection and test records

Fig. 5
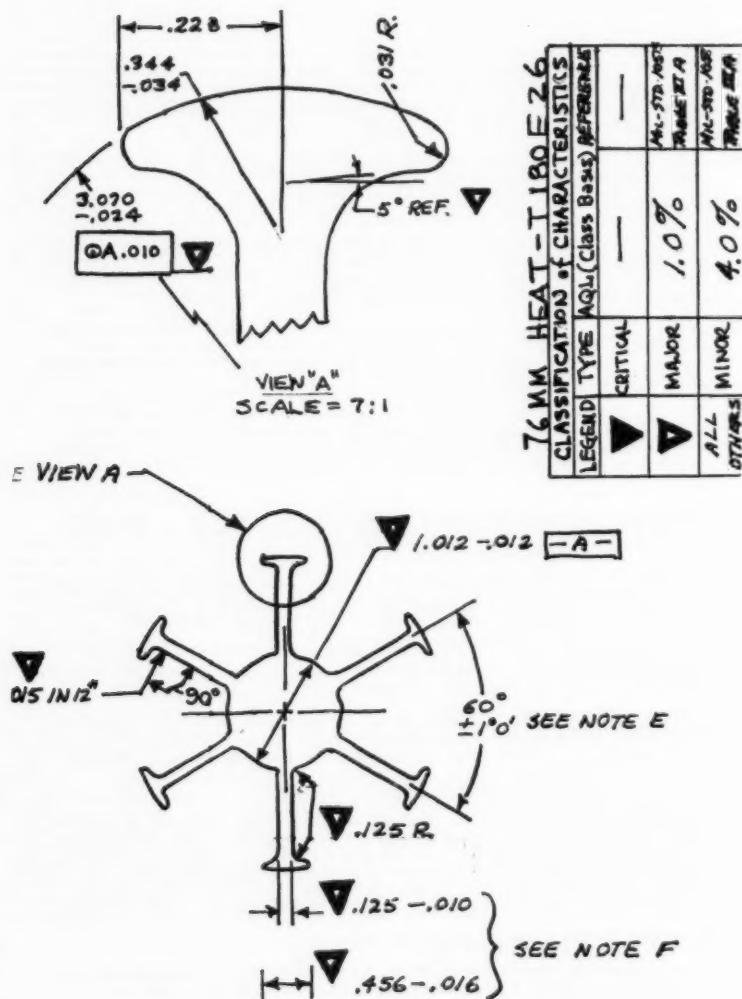
Fig. 6

6. Review of Drawings and Specifications to Determine Potential Trouble Spots
Before Job Starts

Detection and prevention are as synonymous with the quality control as accept-
ance is with inspection. The before-the-fact prevention is certainly more economical
and dramatic than a post-mortem approach. Thus, quality control reviews the drawings
and specifications of new jobs for the purpose of recognizing potential quality prob-
lems, design deficiencies, or methods engineering conditions which might be adverse
to high product yield. The recognition of such problems or deficiencies are brought
to the attention of the proper personnel in a written format as depicted in Figure 7.
This does not end here, inasmuch as there is a follow-up on the corrective action
which was to be taken. You will note on the bottom portion of the report that the
type of corrective action to be taken is required.

STAGE II - INITIAL PRODUCTION RUN

The Initial Production Run Stage represents that portion of the initial manufac-
turing cycle up to approximately 10% to 25% completion of the order. Here is where
the effects of the methods, men, material and facilities upon the quality, quantity,
and economic requirements are closely scrutinized, and altered where necessary. It is
at this stage that the effects must be particularly in consonance with the require-
ments, for what follows is only as good as what has been initially established.
Quality-wise, the costs of detection and prevention in this stage are only a fraction
of how extensive the costs would pyramid to if the undesirable effects were permitted
to prevail during Stage III, or the Regular Production Stage. The quality control
activities in Stage II, which are described below, include reporting method, attri-
bute control charting, process capability studies, instruction to inspectors, audit of
quality, training, development of new techniques and quality control and inspection
teamwork.

1. Product & Process Quality Reporting Method

Since the ultimate measure of quality in process is the actual evidence of the
product yield and mortality, provisions must be made for establishing a method of
maintaining and presenting the "quality score." How should the data be submitted by
inspection? How should the data be collected, analyzed, and presented? How fre-
quently should reports be issued? How sensitive should be the reports? These
questions, which are usually unique to the production-engineered type of job, con-
front our quality control activity.

An effective method of reporting product and process quality in the production-
engineering climate includes:

a. Inspection Reports (Figure 8) are generated by inspection for all types
of components and assemblies at all stages of product growth. This report is carbon-
interleaved, consisting of six copies. Copies are distributed to the manufacturing
supervision, methods engineering, production control, cost control, quality control
and process inspection.

b. The daily feedback of data from the Inspection Report is collated,
analyzed, and reported by quality control in the following manner:

Weekly Quality Summary Report - describes percent defective rates on
weekly and to-date basis for components associated with the various jobs (Figure 9).

Weekly Report of Leading Defects - points out leading defects and trends
of various components and subassemblies (Figure 10).

Monthly Product and Process Quality Report - graphic presentation on a
percent defective basis, the total mortality, scrap and rework (on a monthly basis)
charged to the appropriate manufacturing shop. Control limits ($\bar{X} \neq 2\bar{V}$) are incor-
porated in this report (Figure 11) so that performance can be compared to a standard.
Out-of-control conditions are associated with the leading defect(s) so that correc-
tive action can be directed most effectively.

TO: CHIEF, METHODS ENG'R.	QUALITY PROBLEM REPORT No. 66-60

Component Name: SHELL	Drawing Number: A-8229046
Expenditure Order Number: 93636-01	End Item: Sight Infinity M4+C
Inspected At: 111-4	Lot Number: 1 Pieces: 30
Inspected By: Wm Richey	Inspection Date: 12-8-60

PROBLEM:

1. Material specified on dwg.
   * -problems noted in detail below

ADDITIONAL DATA AND/OR INFORMATION ON PROBLEM:

*1. Dwg. specifies corrosion resisting tubing per
    Mil-T-6736
2. This spec. pertains to Chrome-Molybdenum Steel
   which is not corrosion resistent.
*3. Dwg. specifies finish 5.4 (a),(b),+(c) of Mil Std 171.
    This is an nitric acid bath which would
    cause destruction of component of 4130 Steel.

REMARKS:

Suggest drawing be revised

DATE: 12-9-60

Wm Richey 5707
Wm Richey, Frmn.
INSPECTION OFFICE

ACTION TO BE TAKEN:

Material will be changed on drawing
to be compatible with functional needs

DATE: 12/20/60

JX McGunigle
(SIGNATURE)   9620

Fig. 7

INSPECTION REPORT

TO FOREMAN, MACHINE SHOP #2	FROM PROCESS INSPECTION

DRAWING NO. B-7598011	REV. O	LOT NO. I	WORK PRODUCED IN	
			SHOP	OPERATIONS
NOMENCLATURE STUD	WORK ORDER NO. 06414-01		0556	5, 10, +15
END ITEM NIKE-AJAX	TIME & DATE STARTED 9:00 AM; 2/9/61			
TYPE OF INSPECTION LOT	DEFECTS BROUGHT IN			

SAMPLED			SCREENED			TOTAL	
	MAJOR	MINOR		MAJOR	MINOR		
A.Q.L.	1.5%		QTY. SCREENED	465		QTY. SUBMITTED	500
QTY. SAMPLED	35		QTY. ACCEPTED	251		QTY. ACCEPTED	271
QTY. DEFECTIVE	15		QTY. DEFECTIVE	214		QTY. DEFECTIVE	229

SUMMARY OF DEFECTS

TOTAL NUMBER OF PIECES / DEFECTIVE CHARACTERISTIC	.250 ±.001 .2513 to .2578	.250 ±.001 .248 to .2487	.162 ±.002 .158 to .159	.162 ±.002 .1645 to .169				
19	19							
8		8						
5			5					
14	14			14				
183				183				
CODED CHARACTERISTICS	C-25	C-26	C-26	C-25				
CLASSIFICATION	M	M	M	M				
DISPOSITION	Rwk	Scrap	Scrap	Rwk				
CHARGE TO SHOP AND MACH. GROUP	← —— 0556 —— →							

TIME & DATE FINISHED 2/9/61 3PM	INSPECTION ORGANIZATION 9531	SIGNATURE & NUMBER N. Jones 4075

Fig. 8

WEEKLY QUALITY SUMMARY

TO: OPERATIONS DIVISION Production Supervision
FROM: QUALITY Control SECTION, PRODUCTION ENGINEERING BRANCH
WEEK ENDING: 14 OCT 1960

WORK ORDER:	ITEM:	SUBMITTED FOR INSPECTION THIS WEEK	TO DATE	PERCENT DEFECTIVE THIS WEEK MAT.	PROD.	TO DATE MAT.	PROD.	NUMBER ACCEPTED THIS WEEK	TO DATE	
83205-03	37M/M CART. CASE									
NEW DESIGN	2ND TAPER	—	5753	—	—	3.7	3.1	—	5365	
	PRIOR VARNISH	—	3940	—	—	—	6.7	—	3667	
	AFTER VARNISH	172	3823	1.7	4.4	0.6	1.9	162	3738	A
01077-01	105M/M M115 CASE	2457	4928	0.5	4.7	0.2	3.9	2323	4725	B
97051-04	90M/M PROJECTILE									
MODIFIED DESIGN	BOOM	73	860	—	5.9	1.8	3.7	69	832	C
	CHAMBER	125	675	1.0	7.2	0.3	4.5	115	643	D
	FIN	200	1000	1.0	2.0	1.5	2.2	194	963	
	SPIKE	157	755	—	1.5	0.0	2.0	154	739	
	BODY	110	511	2.5	3.0	1.5	2.7	104	488	
97051-04	90M/M PROJ. ASSY									
MODIFIED DESIGN	SPIKE + BODY	112	359	—	8.9	—	7.2	101	333	E
	FIN + BOOM	279	412	—	6.3	—	8.1	261	379	
91060-03	105M/M PROJECTILE									
NEW DESIGN	BASE	221	6966	—	2.3	0.7	2.8	216	6719	
	FWD. SHEATH	677	7655	—	5.5	—	8.7	640	7115	
	REAR SHEATH	766	10390	—	0.3	2.5	8.7	764	9226	
	SABOT	—	4069	—	—	—	13.9	—	3502	
97021-03	M-13 RANGE FINDER									
MODIFIED DESIGN	ASSEMBLY "A"	77	129	—	13.0	—	7.9	65	118	F
	ASSEMBLY "B"	72	154	—	9.2	—	6.4	65	144	G
	FINAL ASSY.	49	127	—	8.2	—	6.2	45	119	H
98054-01	XM-117 TELESCOPE									
NEW DESIGN	RETICLE ASSY	65	210	1.5	4.5	0.5	3.8	62	201	
	FINAL ASSY.	40	205	—	5.0	—	7.3	38	190	
07592-01	M-17 CART. ACT. DEV.									
NEW DESIGN	ASSEMBLY #1	115	501	1.0	4.2	0.3	3.7	109	481	
	ASSEMBLY #2	172	595	—	3.5	—	7.1	166	553	
	FINAL ASSY.	98	450	—	4.1	—	8.0	94	414	
09528-1	XM-31 FUZE									
NEW DESIGN	STATION #1	57	125	—	7.0	—	4.8	53	119	I
	STATION #2	42	110	—	4.8	—	6.4	40	103	
	STATION #3	51	105	—	5.9	—	7.6	48	97	
	FINAL ASSY.	35	75	—	20.0	—	9.3	28	68	

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Fig. 9

LEADING DEFECTS—WK. QUALITY

TO:		FROM: QUALITY Control SECTION, PRODUCTION ENGINEERING BRANCH		WEEK ENDING: 14 OCT '60				
WORK ORDER:	ITEM:	SUBMITTED FOR INSPECTION		PERCENT DEFECTIVE				NUMBER ACCEPTED
				THIS WEEK		TO DATE		
		THIS WEEK	TO DATE	MAT.	PROD.	MAT.	PROD.	THIS WEEK	TO DATE

EXPLANATION OF LEADING DEFECTS (14 OCT '60)

Ⓐ PROFILE OVER SIZE — 10 PCS

Ⓑ SCRATCHES — 100 PCS
1.250 – 12 UNF-2B THD – 28 PCS

Ⓒ 2.7500 +.0003 O.D. — 4 PCS

Ⓓ 2.125 – 16 UNF-2B THD – 10 PCS

Ⓔ VOLTAGE BREAKDOWN – 11 ASSYS.

Ⓕ CONCENTRICITY OF "C" WITH "D" — 12 ASSYS.

Ⓖ ELEVATION ERROR — 7 ASSYS.

Ⓗ PLUMB TRAVEL — 2 ASSYS.
HORIZONTAL ERROR — 2 ASSYS.

Ⓘ ARMING SPIN TEST — 4 ASSYS.

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Fig. 9 (cont)

OPER. DIV.

SUMMARY OF LEADING DEFECTS (WK.)

Sheet 1 of 5

LEGEND:
○ = indicates processing problem area
□ = indicates material problem area

Fig. 10

Fig. 11

There are additional aspects of the reporting system in which brief reference will be made. These have proved important in the area of presenting continuing evidence of the actual product quality. Such reports are:

First Piece or Layout Inspection Report Used to record results of first piece inspection during processing and/or layout inspection on new or modified castings Figure 12.

Frequency Distribution Report - Where inspection readings are made in variables and the information is to be recorded, use is made of the Frequency Distribution Report Figure 13. This report can be attached to the Inspection Report or be embodied in with a report of product or process quality which is fed back to methods or design engineers. Analysis of the frequency distribution is accomplished by quality control. We look upon the frequency distribution as a tool, as well as a concept. This is an effective way to condense and summarize continuous data and permit the reader to quickly form an idea as to what the central tendency and variability approximate.

2. Attribute Control Charts ("p"and "c" charts per product and shop)

The attribute control charts ("p" and "c") charts, which are concerned with judging the stability of the fraction defective and number of defects generated in the process, are good tools that can assist in identifying quality problem areas. Using these charts, a shop, process or product can be justifiably considered stable or unstable. The installation of such charts is either based upon past data about the particular job or a similar one, or assuming what the sample size and fraction defective can logically approximate. In Figure 14 is an example of "p" chart employed on a new job.

3. Process Capability Studies

Process capability studies find wide use during the "Initial Production Run Stage" as well as during the "Process Stabilizing and Regular Production Stage." Failures to meet reasonable specifications result from (1) inadequate process capabilities and/or (2) inadequate operating controls. Only the knowledge of the existing process capability can help in diagnosing the cause or causes of the failure. Knowledge of machine capabilities and control allowance requirements avoids the dissatisfactions which result from inability to meet specifications and the excess costs involved in over tooling. The idea of having identical sized parts coming from a process, whether of short run or long duration, is certainly false. In actuality, it is customary to find a central tendency with larger and smaller scattering on both sides of the central tendency.

The application of process capability concepts in the production-engineering climate is not limited by the generally irregular production or newness of components and assemblies. Due to the nature of the smaller quantities on our order, smaller sample sizes are used in conjunction with capability studies. Sample sizes vary between 50 to 100 pieces. Naturally we lose a certain degree of reliability of our interpretations as the sample data decreases. (Data on averages become more reliable as the square root of the sample size, while data on spread become more reliable as the square root of twice the sample size). However, for expediency sake, coupled with our willingness to risk a certain decrease in accuracy of our answer, we employ capability studies using 50 to 100 pieces on potential trouble spots before the fact, or leading defects during the fact. The important thing is that the statistical analysis on small samples still gives the best estimate possible of the process and product when contrasted to a practical decision. An example of such a capability study is presented in Figure 15.

4. Quality Control Instructions to Process Inspection

The carrying out of a quality control technique, method, or plan involves in many cases, assistance and participation by Process Inspection. Written instructions

FIRST PIECE OR LAYOUT INSPECTION REPORT

TO: MACHINE SHOP #1	FROM: PROCESS INSPECTION

1. END ITEM: RANGE FINDER	2. OPN NO: 5/35	3. TYPE OF INSPECTION: ☑ FIRST PIECE ☐ LAYOUT

4. DRAWING NUMBER: B-7693178	5. LOT NO: 1/3	6. NOMENCLATURE: HOUSING	7. X.O. NUMBER: 89627-01

8. DIMENSION OR ATTRIBUTE	9. MEAS. OR OBS.	10. REMARKS	8. DIMENSION OR ATTRIBUTE	9. MEAS. OR OBS.	10. REMARKS
3.750+.002	3.7512	OK			
2.387+.005	2.3915	OK			
1.907±.010	1.908	OK			
1⅛ ± 1/64	1⅛	OK			
32 rms	30 rms	OK			
0.8750-.0003	0.8742	✗			
5.250+.010	5.255	OK			
⅛ rad.	⅛	OK			
⊕.010 Ⓐ	.007	OK			
⊥.010 Ⓑ Ⓒ	.009	OK			
45°±1°	45°27′	OK			
HARDNESS RockWell 40C MINIMUM	47/55C	OK			
.450±.020	.463	OK			
.041+.005R	.043	OK			
.900 MAX	.875	OK			

11. THE PIECE IS: ☐ ACCEPTABLE ☑ NOT ACCEPTABLE Correct 0.8750-.0003	12. DATE: 9/26/61
	13. SIGNATURE: mm Smith 5307

Fig. 12

FREQUENCY DISTRIBUTION VARIABLE MEASUREMENTS			1. ☐ INCOMING MATERIAL ☐ PROC. INSP. (Comp. Sub-Assy, Compl. Assy) ☒ PROCESS OPERATIONAL ACCURACY		
2. DRAWING NUMBER: D-7529371	3. NOMENCLATURE: LEVER			4. END ITEM: RANGE FINDER – M 13	
5. WORK ORDER: 97065	6. SOURCE OF ITEM:				
	6a. FRANKFORD ARSENAL		6b. CONTRACTOR:	6c. NATIONAL STOCK	
7. LOT NUMBER:	COST CENTER: 8620	MACHINE NUMBER: 179-A		REQUISITION NUMBER:	
8. ☐ ELECTRICAL ☒ MECHANICAL ☐ OPTICAL	OPERATION NUMBER 15	OPERATOR NO: 5307	CONTRACT NUMBER:	DEPOT OR ARSENAL:	

9.	9a. MEASUREMENT:	9b. DISTRIBUTION TALLY					9c.
			f	d	fd	fd²	ACTION
	.448						
	.447						
	.446						
	.445	I	1	+5	5	25	
	.444	II	2	+4	8	32	
	.443	III	3	+3	9	27	
	.442	LHT	5	+2	10	20	
	.441	LHT II	7	+1	7	7	
	.440	LHT LHT	10	0	0	0	
	.439	LHT LHT LHT	15	-1	-15	15	
	.438	LHT LHT I	11	-2	-22	44	
	.437	LHT LHT	10	-3	-30	90	
	.436	LHT	5	-4	-20	80	
	.435	III	3	-5	-15	75	
	.434	II	2	-6	-12	72	
	.433	I	1	-7	-7	7	
	.432				-82	494	
	.431						
	.430						

(left margin, vertical text: LENGTH　.430 +.013　DIMENSION OR CHARACTERISTIC MEASURED:)

(right margin, vertical text: PROCESS CAPABLE OF MEETING .013 TOLERANCE'S SUGGEST .007 SHIFT DOWNWARD)

m = 75	$\frac{UL-\overline{X}}{\sigma} = \frac{.443-.439}{.002} = +2.0$
$\Sigma X = 32.92$	
$\overline{X} = 0.439$	$\frac{LL-\overline{X}}{\sigma} = \frac{.430-.439}{.002} = -4.5$
$\sigma = 0.002$	
$\overline{X}+3\sigma = 0.445$	Area Within = .9773 - .00001
$\overline{X}-3\sigma = 0.433$	= 97.7%
	Area Exceeding = 2.3%

10. REMARKS: $\overline{X}$ = Assumed origin + (interval)$\left(\frac{\Sigma fd}{m}\right)$ $\overline{X} = 0.440 + (.001)\left(-\frac{82}{75}\right) = 0.439$	$\sigma = (interval)\sqrt{\frac{\Sigma fd^2}{m} - \left(\frac{\Sigma fd}{m}\right)^2}$ $\sigma = (.001)\sqrt{\frac{494}{75} - \left(\frac{82}{75}\right)^2}$ $\sigma = 0.002$	
11. DATE: 11-7-60	12. INSPECTION AREA: 9510	13. INSPECTOR: 0520

Fig. 13

Fig. 14

must be made available to the process inspectors to prevent misunderstandings, oversights and the like. This approach affords accurate communication and is of particular importance in the production-engineering climate, because many times you don't get a second chance to run the job or find that a second lot will be processed. An example of a "Quality Control Instruction" is given in Figure 15. Such instructions can include variable control charting instructions, procedures for carrying out a special test, the change in sampling frequency, the initiation of a process capability study, or the application of a new piece of test equipment.

5.   Audit Product & Process Quality Results & Initiate Corrective Action

Auditing of product and process quality results is usually the forerunner of identifying and solving our significant quality problems. Significant, in the production-engineering case, implies out-of-control mortality, heavy dollar losses, noticeable interruptions in processing, functional shortcomings, inspection inaccuracies, unrealistic specifications, etc. Auditing includes daily shop visits to observe attribute and variable control chart results; results of special tests: review of daily, weekly and monthly quality trends and costs; and evaluation of incoming and outgoing quality. Corrective action on problem cases in the production-engineering climate usually means a team approach. The team brings together a small number of people, each of whom has something different to contribute to the solution of the problem. The nature of the problems can touch upon methodizing, machine, men, material, inspection, gaging, tolerancing and the like. The corrective measures in process and product control is frequently elusive. While there are basic statistical tools (capability study, control chart, regression study, significance tests) that can be used by quality control, there are times when getting an answer still appears futile. It is here that our team approach proves of immeasurable value.

6.   Training in Quality Control Techniques

When training in quality control methods and techniques is provided to process inspectors, methods engineers, and supervision, their background and place in the organization is considered, as well as the needs to which the training will be applied. The training attempts to provide simple concepts or fill a particular need during the class meeting, which average 2 hours per meeting. Ample handouts and demonstrations accompany each class session. Regardless of the group of individuals being exposed to the training, interest must be aroused in order to take the statistical quality control concepts and application away from the "mystic" stage and into the useful tool stage. Actually we look upon training from the standpoint of a "Problem-Solving Clinic."

Simple demonstration devices are used wherever possible. Little or no homework is required, since on-the-job application can indicate the degree of proficiency.

Subject matter covered includes:

> Frequency distribution study
> Variable control charting
> Attribute control charting
> Attribute sampling
> Variable sampling
> Statistics made easy
> Accuracy in reporting
> Inspection short-cuts
> Gaging accuracy
> Inspection-production relationships

We feel that training in quality control methods and techniques is a continuing thing. Personnel turnover, greater amplification of basic fundamentals, newer ideas, etc. necessitates continuous training. An example of a training handout is presented in Figure 16.

| FROM: Ind Grp
Operations Div.
Prod. Eng'rg. Br.
TO: Chf, Mfg. Br. (8000) | QUALITY CONTROL
INSTRUCTION | NO. 30-60
REV. ____ DATE 12-6-60
PAGE 1 OF 1 |

SUBJECT: Statistical Method of Quality Control, Manufacture of Ammunition Cartridge, NATO, Blank, 7.62MM IM 82. Weight of Powder Charge. Blank Loading 8833.

PURPOSE To establish Quality Control limits for weight of powder charge at the operation mentioned in the subject.

REFERENCE Inspection data taken from August through November 1960

INFORMATION OR PROCEDURE:

1. 9520: Take a sample of five cartridges from each loading machine in operation at least every thirty minutes, and more frequently, if necessary. Inspect for visual defects, remove wad, and weigh, using a chain-o-matic balance, powder charge to the nearest .01 grain. Record weights, compute averages and extreme variations and plot on control charts. The following quality control limits shall apply:

2. 8833 and 9520: Observe the following limits:

	Limits for Avg. of Samples of 5	Limits for E.V. or Samples of 5
Weight of powder	18.20 - 18.80 grains	.50 grains

3. 9520: When visual defects are encountered or when an average or extreme variation falls outside the prescribed control limits, shut down the machine for adjustment. Subsequent to adjustment, recheck weights and, if satisfactory, permit the machine to operate; otherwise, shutdown the machine again for additional adjustment.

4. 8833: Make corrections and adjustments when requested by 9520.

5. 9650: Will supply necessary forms and charts.
AJWard/mp/21254
DISTRIBUTION:

8800 - Mr. Penn, 212-1	9650 - Mr. Braverman, 228-3
9500 - Mr. Furmanski, 228-1	9650 - Mr. Ward, 228-3
9600 - Mr. Hewitt, 228-3	9520 - 212-1 (3)
9600 - Mr. Gatter, 228-3	9650 - 228-3
9621 - Mr. Walters, 228-3	
9520 - Mr. O'Neill, 212-1	
8833 - Mr. Fulmer, 209-3 (2)	

CONCURRENCE: _____ APPROVED: _____
J. BRAVERMAN   A. R. HEWITT
Chief, Quality Control Sect (9650)   Chief, Prod. Eng'rg. Br. (9600)

Fig. 15

Relationship Among Specification, Individual, & Control Limits

Training Handout #2
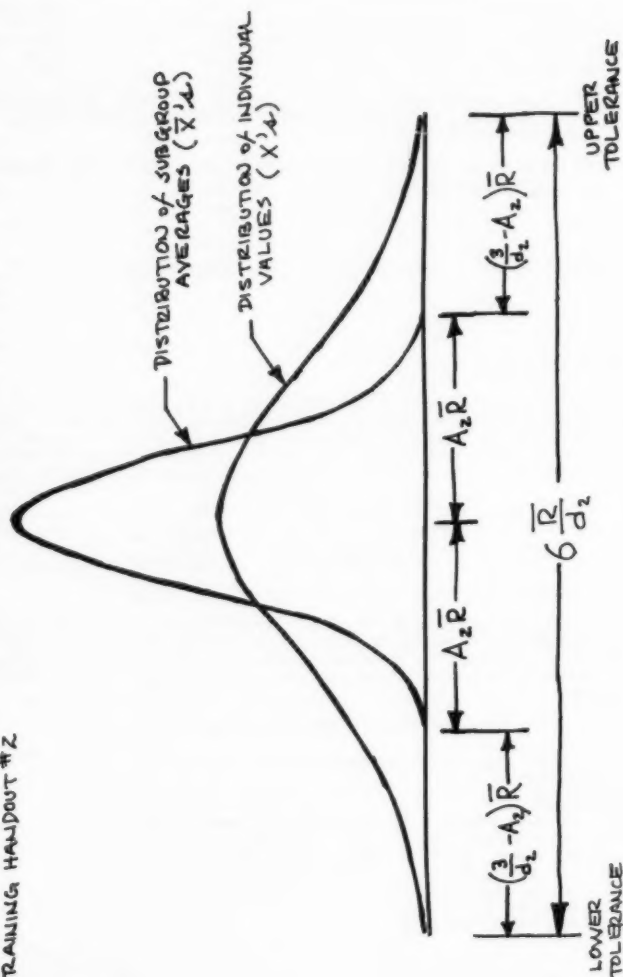
Fig. 16

7. Development of New Techniques for Analysis of Quality Problems

The implication at this point of developing new techniques for attacking and analyzing quality problems is perhaps better described in the familiar phrase, "there is a better way to do it - find it." There is no question that often the statistical and engineering man-hours involved in handling a quality problem becomes quite time consuming, laborous, and costly, and does not provide the answers in sufficient time for the industrial situation. This need, particularly in our type of manufacturing situation, has forced quality control to explore short and rapid statistical techniques, nomographs, tables, and charts as an adjunct to the more sophisticated statistical techniques. In actuality, we find that a dichotomous approach in the use of statistical techniques in the production-engineering climate is the best. The more accurate, detailed tests and the short and rapid tests are both considered, with the appropriate type of test applied with the need. Naturally, with the short and rapid tests, we realize a decrease in efficiency of our answer. Basically, it is a matter of balancing the decrease in accuracy of one answer with the increase in precision, time, and manpower. In Table I is listed a comparison of some detailed and rapid tests.

8. Coordinate Quality Control & Process Inspection Effort

The coordination of quality control and process inspection activities is essential during the Initial Production Run stage. This is necessary in view of the variety of quality control techniques employed and problems recognized by process inspection. An example of this coordination is depicted in Figure 17. Coordination of effort is of importance in this stage since many new ideas and techniques are being tested for feasibility of application during Stage III.

STAGE III - PROCESS STABILIZING & REGULAR PRODUCTION

In Stage III, there is a general stabilizing of quality effort. Some settling-down or elimination of significant defects occurs. Naturally stabilizing refers to all those contributions of the process which can contribute to product or process quality shortcomings. This stage continues through to the completion of the order.

1. Comprehensive Management Report of Product & Process Quality

Comprehensive reporting in Stage III is concerned with keeping management informed as to the product quality, types of leading defects, out-of-control conditions, losses due to scrap, and corrective measures taken to correct quality discrepancies. Reports to and from management regarding product and process quality also clarify the problems that must be solved.

An important fact is considered in our approach to reporting. We strive for clear, concise reports. It should be pointed out that in the production-engineering type climate, with its wide variety of items of low and medium density, it is often easy to develop reports which "snow-ball" in size to accommodate for the many components, and processes. As a result, the reports become cumbersome and easily lose their effectiveness. In an effort to prevent this, reporting attempts to incorporate simple histograms, line charts, and numerical summaries, and only highlight out-of-control conditions. It is truly a challenge to present a brief report which contains the key elements and really captures management's attention. Actually, the purification of reporting to specifically meet your company's needs is a continuing problem.

2. Statistical Studies on Product and Process Quality Problems

The statistical techniques used in our production-engineering climate are the frequency distribution analysis, correlation analysis, significance tests, analysis of variance, and design of experiments. Some of our applications of each of these five techniques are described below:

TABLE 1

Problem #1 - Close tolerance, leading defect, potential processing problem, or
capability of process desired

A. Customary Statistical Technique: Process Capability Study

1.1 Select 100 to 200 consecutive pieces from an approved process

1.2 Study the frequency distribution of readings for:

$$\overline{X} = \frac{X_1 + X_2 + \dots + X_m}{m}$$

$$S = \sqrt{\frac{X_1^2 + X_2^2 + \dots X_m^2}{m} - \overline{X}^2} \qquad \hat{\mathcal{T}} = \sqrt{\frac{m S^2}{m-1}}$$

where,
$\overline{X}$ = arithmetic mean
X_1, X_2 = specific observed values
m = sample size
S = standard deviation of sample
$\hat{\mathcal{T}}$ = standard deviation of population (estimated)
$6\hat{\mathcal{T}}$ = process capability

1.3 Analyze frequency distribution for skewness and kurtosis

$$a_3 = \frac{m_3}{(m_2)^{3/2}} \; (SKEWNESS) \qquad a_4 = \frac{m_4}{(m_2)^2} \; (FLATNESS)$$

where,
$$m_2 = \frac{\leq (x - \overline{x})^2}{m} \qquad m_4 = \frac{\leq (x - \overline{x})^4}{m}$$

$$m_3 = \frac{\leq (x - \overline{x})^3}{m}$$

1.4 Solve for the estimated population fraction defective from sample results
by performing the following:

$$Z_1 = \frac{Upper \, Limit - \overline{X}}{\mathcal{T}} \qquad Z_2 = \frac{Lower \, Limit - \overline{X}}{\mathcal{T}}$$

$$A_1 = Area \; from -\infty \; to \; Z_1$$
$$A_2 = Area \; from -\infty \; to \; Z_2$$

where,
$A_1 - A_2$ = area between specification limits (fraction effective)
$1 - (A_1 - A_2)$ = area outside specification limits (fraction defective)
A_2 = fraction defective below lower specification limit
$1 - A_1$ = fraction defective above upper specification limit

B. Short-Cut Technique: Limited Process Capability Study

1.1 Select 15 consecutive pieces from an approved process

1.2 Visually study frequency distribution for "normality"

1.3 Determine range (R) of 15 pieces

1.4 Estimate standard deviation of individual values ($\mathcal{T}$) from range (the range
can be used for estimating the standard deviation only when the universe
being sampled is near normal, and in the wide majority of industrial quality
control situations, this is the case)

$$\mathcal{T} = (R)(0.2880) \qquad 6\mathcal{T} = process \; capability$$

TABLE 1 (cont.)

1.5 Estimate the population fraction defective from sample results by referring below to the circular nomograph for "Area Under Normal Curve."

1.6 The use of sample quasi-ranges in estimating the standard deviation can also be employed to realize an increase in efficiency of the $\hat{\sigma}$. For a sample size of 15 pieces, a 92% efficiency for estimating $\hat{\sigma}$ can be realized by:

$$\hat{\sigma} \doteq (.1546) (w_0 + 1.2011\ w_1)$$

where w_0 = range between largest and smallest number

w_1 = range between second largest and second smallest number

AREA UNDER NORMAL CURVE
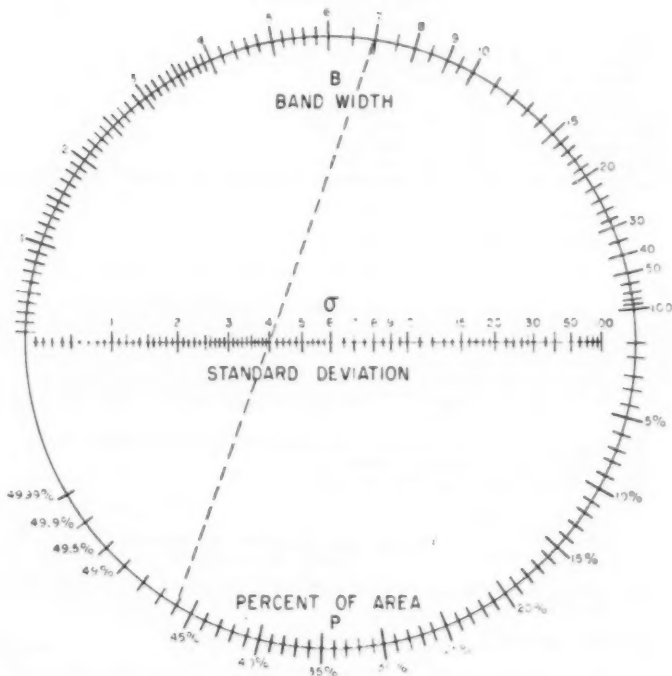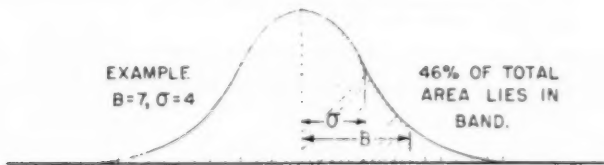
NORMAL CURVE AREA NOMOGRAM

TABLE 1 (cont.)

Problem #2 - Significant defect, processing problem, important characteristic, or potential quality difficulty

A. Customary Statistical Technique: Variable Control Charting

    2.1 Accumulate about 25 subgroups (sample sizes of 4, 5 or 6 per subgroup) of measurements, where each subgroup is usually selected from the machine every few hours

    2.2 Calculate control limits for averages ($\bar{X}$) and ranges (R) of subgroups

$$\bar{\bar{X}} = \frac{\Sigma \bar{X}}{m} \qquad UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \bar{R}$$
$$\bar{R} = \frac{\Sigma R}{m} \qquad LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \bar{R}$$
$$UCL_R = D_4 \bar{R}$$
$$LCL_R = D_3 \bar{R}$$

where,
$\bar{\bar{X}}$ = grand average of subgroup averages
$\bar{R}$ = average range of subgroup ranges
m = number of subgroups
$UCL_{\bar{X}}$ = upper control limit for average chart
$LCL_{\bar{X}}$ = lower control limit for average chart
UCL_R = upper control limit for range chart
LCL_R = lower control limit for range chart
A_2, D_3, D_4 = factors for average and range charts depending upon sample size of subgroup

$n = 4$, $A_2 = 0.73$, $D_4 = 2.28$, $D_3 = 0$
$n = 5$, $A_2 = 0.58$, $D_4 = 2.11$, $D_3 = 0$
$n = 6$, $A_2 = 0.48$, $D_4 = 2.00$, $D_3 = 0$

    2.3 Compare subgroup averages and ranges with control limits to determine constant cause system (values within control limits) or assignable cause system (values outside control limits)

    2.4 Determine variability of individual measurements and estimate of process from: $\sigma' = \dfrac{\bar{R}}{d_2}$ $6\sigma' = $ estimate of process

where,
σ = estimate of standard deviation of universe of individual measurements
$\bar{R}$ = average range of subgroup ranges
d_2 = factor for estimating (σ) from ($\bar{R}$):

$n = 4$, $d_2 = 2.059$
$n = 5$, $d_2 = 2.326$ (The d_2 factor assumes sampling
$n = 6$, $d_2 = 2.534$ from a normal universe)

    2.5 Compare the estimate of process ($6\sigma'$) to tolerance range, and take appropriate action.

B. Short-Cut Technique: Limited Variable Control Charting

    2.1 Set up temporary control limits on the average ($\bar{X}$) and range (R) charts for the given dimension without benefit of any prior information or without any preliminary process capability study.

    2.2 The temporary control limits are set up under the assumption that the six sigma (6σ) spread of the distribution obtained from the process coincides with the tolerance range of the drawing. Thus, if T is the drawing tolerance range, then

TABLE I (Cont.)

$$\frac{T}{\sigma} = 6\sigma$$
$$\sigma = \frac{T}{6}$$

however,

$$\sigma = \frac{\overline{R}}{d_2} = \frac{T}{6}$$
$$\overline{R} = \frac{(d_2)\,(T)}{6}$$

and for sample sizes of 5, where $d_2 = 2.326$
we obtain:

$$\overline{R} = 0.388T$$

2.3 Substituting this expression for $\overline{R}$ into the equation for control limits, we have: (For $n = 5$)

$$UCL_{\overline{x}} = \overline{X}_m \neq 0.23T$$
$$LCL_{\overline{x}} = \overline{X}_m - 0.23T$$
$$UCL_R = 0.82T$$
$$LCL_R = 0$$

where,

$\overline{X}_M$ = assumed mean of drawing

T = tolerance range

2.4 Where the defect or quality problem has improved, variable control charts can be either removed, or continued using a smaller subgroup sample size of perhaps 2 pieces. The control limits are now computed by calculating the $\overline{R}$ from about 10 to 15 sample subgroups ($n = 5$) immediately preceding the adjustment in subgroup sample size, and solving for:

$$\sigma = \overline{R}/d_2$$

Next calculate

$$UCL_{\overline{x}} = \overline{X}_M \neq A\sigma$$
$$LCL_{\overline{x}} = \overline{X}_M - A\sigma$$
$$UCL_R = D_2\,\sigma$$
$$LCL_R = D_1\,\sigma$$

where,

$A = 2.12$
$D_1 = 0$ } for $n = 2$
$D_2 = 3.69$
$\overline{X}_M$ = mean of drawing

TABLE I (Cont.)

Problem #3 - Control of process and product mortality

A. Customary Statistical Technique; Attribute Control Chart

3.1 To determine the presence of assignable causes of variation associated with fraction defective rates, consider the attribute control chart ("p" Chart).

3.2 Using the standard deviation of the fraction defective as $\sqrt{\frac{p'(1-p')}{n}}$ compute control limits as follows; (assume $p' = \bar{p}$)

$$UCL_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad LCL_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where,

$\bar{p}$ = observed average fraction defective
p' = true process average fraction defective
n = number inspected (daily, weekly, monthly, etc.)
UCL_p = upper control limit for fraction defective
LCL_p = lower control limit for fraction defective

B. Short-Cut Technique; Limited Attribute Control Charting

3.1 Determine control limits for "p" chart by employing circular nomograph described below, which solves for $3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$
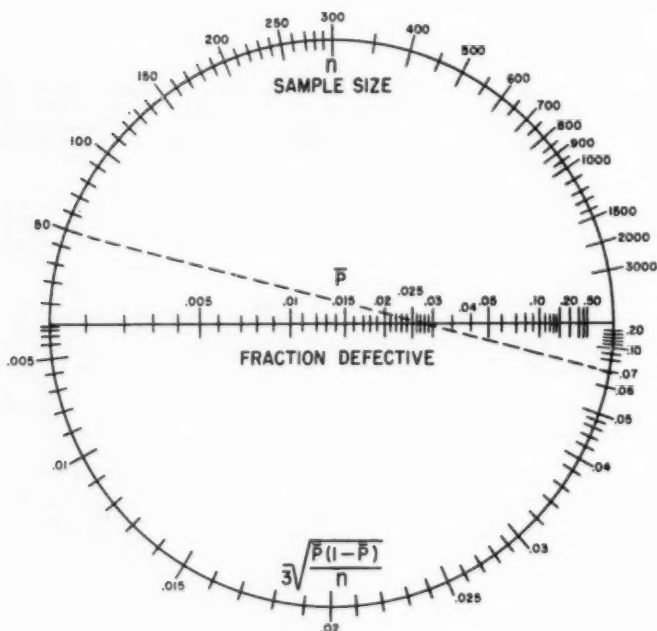
TABLE 1 (Con't.)

Problem #4 - Investigate the relationship between two variables, or the effect that the related variable x has upon the basic variable y.

A. Customary Statistical Technique: **Correlation Study**

4.1 Solve for the regression line, where

$$SLOPE = b = \frac{m \Sigma XY - \Sigma X \Sigma Y}{m \Sigma X^2 - (\Sigma X)^2}$$

$$INTERCEPT = a = \frac{\Sigma Y - b \Sigma X}{m}$$

$(m = pairs\ of\ observations)$

$$REGRESSION\ LINE = Y_n = a + bx$$

$$CORRELATION\ COEFFICIENT = \lambda = \sqrt{\frac{a \Sigma Y + b \Sigma XY - m \bar{Y}^2}{\Sigma Y^2 - m \bar{Y}^2}}$$

$$STANDARD\ ERROR\ ESTIMATE = S_y = \sqrt{\frac{\Sigma Y^2 - a \Sigma Y - b \Sigma XY}{m}}$$

B. Short-Cut Technique: **Limited Correlation Study**

4.1 Test whether two variables are correlated by checking the correlation between their ranks, using the Spearman rank - correlation test.

4.2 Compute

$$K = \frac{m(m+1)(m-1) - 6(\Sigma d^2 \pm 1)}{m(m+1)\sqrt{m-1}}$$

where,

$$\pm = \begin{cases} + & if\ 6 \Sigma d^2 < m(m+1)(m-1) \\ - & if\ 6 \Sigma d^2 > m(m+1)(m-1) \end{cases}$$

n = number of pairs of observations

d^2 = sum of squared differences in rank

* K = standard normal variable

* K is normally distributed, but its mean and standard deviation are 0 and 1; knowing K, you can refer to the table of the standard normal distribution to find the probability of a value larger than any particular K.

Problem #5 - Significance tests on data

A. Customary Statistical Technique: **Significance Testing**

5.1 Test to determine if different samples belong to normal populations having the same mean and variance (L_0 test)

$$L_0 = \left(\frac{S_1^2 \cdot S_2^2 \cdots S_K^2}{S_0^2 \cdot S_0^2 \cdots S_0^2}\right)^{\frac{1}{k}}$$

where,

s_1^2 = within sample variance

s_0^2 = variance based upon the derivation of all N observations about their mean $\bar{X}$

(The distributions of L_0 have been approximated and tables have been prepared).

k = number of samples

TABLE 1 (Con't.)

5.2 Test to determine if different samples belong to normal populations of the same variance (L_1 test)

$$L_1 = \left(\frac{S_1^2 \cdot S_2^2 \cdots S_K^2}{S_a^2 \cdot S_a^2 \cdots S_a^2} \right)^{\frac{1}{K}}$$

where,

S_1^2 = within sample variance
S_a^2 = mean of the within-sample variances

5.3 Test to determine the difference in variability in two independent samples selected from normal populations where the means are the same (F test)

$$F = \frac{\hat{q}_1^2}{\hat{q}_2^2}$$

where,

$$\hat{q} = S \sqrt{m/m-1}$$

$$S = standard\ deviation\ of\ sample$$

5.4 Test to determine if there is a difference between two sample means where the standard deviation of the population is not known, but assumed to be the same for both populations (t test)

$$t = \frac{\overline{X_1} - \overline{X_2}}{\hat{q} \sqrt{m_1 + m_2 / m_1 m_2}}$$

$$\hat{q} = \sqrt{\frac{m_1 S_1^2 + m_2 S_2^2}{m_1 + m_2 - 2}}$$

where,

$\hat{q}$ = estimate of standard deviation of the population
$S_1 \& S_2$ = sample standard deviations
$\overline{X}_1 \& \overline{X}_2$ = sample means

B.   Short-Cut Technique: Limited Significance Testing

5.1 A 95% confidence interval for the median * can be obtained from a sample (n) by determining the integer nearest to

$$\frac{m+1}{2} - \sqrt{m}$$

and then counting down this number from the sample largest reading and counting up this number from the sample smallest reading. It is necessary that the readings be ranked.

     * (If the distribution is sufficiently symmetrical, the median is a reasonable substitute for the mean).

5.2 A test to compare the averages of two populations on the basis of two independent samples can be performed by the use of the Wilcoxon two-sample test. All observations of both samples are combined and ranked. The approximate standard normal variable (K) is calculated by

$$K = \frac{2R \pm 1 - m(N+1)}{\sqrt{\dfrac{m(N+1)(N-m)}{3}}}$$

TABLE 1 (Con't.)

where,

R = sum of the ranks of either sample
n = sample size from which R is taken
N = number of observations in both samples

$$\pm = \begin{cases} - \text{ if } 2R > m\,(N+1) \\ + \text{ if } 2R < m\,(N+1) \end{cases}$$

(Having the value K, you refer to the tables of the standard normal distribution to find the required probability. Such tables show the probability of a value larger than any particular K. The probabilities in these tables are usually either upper-tail type or the two-tail type. As a rough guide to the significance attached to your K value, if K is 1.96 or greater, it can be assumed that there is more than chance between or among the samples. This is considering a 95 percent probability that a normal distributed variable is within ⫫ two standard deviations of the mean. That probability is 95 percent for K = 1.96).

5.3 A test to compare the averages of several populations on the basis of several independent samples can be had by employing the Kruskal-Wallis test. All observations of all samples are combined and ranked. The standard normal variable is computed from

$$K = \sqrt{2H} - \sqrt{2k-3}$$

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{m_i} - 3\,(N+1)$$

where,

R_i = sum of ranks in i-th sample
n_i = number of observations in i-th sample
N = number of observations in all samples
k = number of different samples

(See the explanation above in 5.? for handling K).

Teamwork of Quality Control and Process Inspection

Quality Control

1. Provide Lot Sampling Plans and Machine Inspection Plans

2. Develop Reporting System
   Analyze Data
   Issue Appropriate Reports of Quality

3. Analyze Data
   Suggest Approaches to the Study of Problems

4. Develop and Test Sampling Plans

5. Develop and Test Quality Control Plans and Procedures

6. Develop and Recommend Application of Preventive Measures

7. Measure Dollar Value of Scrap and Rework and Study Shop and Process Quality Trends

8. Experiment With New Gaging and Measuring Devices

9. Analyze and Report Inspection Findings on Contractors' Products

10. Provide Training and Orientation in Quality Control Techniques

11. Study Outgoing Quality Rates and Make Recommendations to Process Inspection

12. Monitor, Review, and Maintain Case Histories

Process Inspection

1. Provide First Piece Inspection, Machine Inspection, Lot Sampling Inspection, and 100% Inspection

2. Feed back Product and Process Quality Data

3. Provide Daily Shop Trouble Shooting of Product and Process Quality Problems

4. Apply New, Modified or Revised Sampling Plans

5. Apply and Assist in Developing Quality Control Plans and Procedures

6. Apply Preventive Measures

7. Identify and Report Defective Material

8. Test New Gaging and Measuring Devices

9. Evaluate Contractor's Products

10. Apply New Quality Control Techniques

11. Adjust Inspection Activity in Line With "Customer Needs"

12. Prepares Reports, Rejection, First Piece, Lot Inspection, Frequency Distribution, Quality Problem, Quality Appraisal, Material Review Committee, etc.

Figure 17

a. Frequency Distribution Analysis

    (1) Process capability studies
    (2) Dimensional changes of parts during various stages of processing
    (3) Ballistic results of ammunition
    (4) Performance results during environmental tests

b. Correlation Analysis

    (1) Physical change in ammunition after heat-treatment
    (2) Dimensional changes in fire control and ammunition parts with
         the application of various processing techniques.
    (3) Relationship of ammunition accuracy between results at 300 yards
         compared to results at 600 yards.
    (4) Absenteeism of inspectors due to weather conditions.

c. Significance Tests

    (1) Comparison of the difference in ammunition accuracy between
         defect and defect-free cartridges.
    (2) Comparison of the average and variability of product quality
         measurements from various sources of supply.
    (3) Comparison between an expected test result and an observed test
         result for ammunition.
    (4) Comparison of the accuracy of decisions between types of
         inspectors.
    (5) Comparison of inspection results when using different test
         fixtures.

d. Analysis of Variance

    (1) Study the effect that different ammunition and different guns
         have upon accuracy results.
    (2) Study the effect that working days have upon male and female
         inspectors.
    (3) Study the effect that different pull-test methods with bonded
         assemblies have upon pull test results.
    (4) Study the effect of machines and operators upon product quality.

e. Design of Experiments

    (1) Design of test to evaluate ammunition accuracy and gun effect at
         different ranges, considering order of firing ammunition in guns,
         method of cooling, and period of gun usage.
    (2) Design of test to evaluate a new process
    (3) Design of test to study functional results of new design under
         varying loads, temperatures, pressures, etc.

The concepts and techniques associated with these five aforementioned statistical techniques can be had by making reference to the variety of excellent statistical textbooks which are available; some are listed in the reference of this paper.

3. Review and Adjust Sampling Plans With Need

Product variability, economics of inspection, actual dollar value of material, outgoing quality rates, changes in requirements, or modifications in processing, are sufficient to cause a re-evaluation of inspection plans for possible adjustment or replacement. The features of the "O-C" Curve, AOQ Curve, sample size, acceptance-rejection criteria, Amount of Inspection Curve, and administration of the plan are studied once again. For example, consistently good, outgoing quality can trigger off a change from a single sampling plan on a class basis to a multi-level continuous

sampling plan on a characteristic basis, resulting in very noticeable savings in inspection man-hours. Or a single sampling plan possessing a discriminating "O-C" Curve will be replaced by a double sampling plan if we observe the presence of very good or very bad quality. Then again, machine inspection with variable control charts might be reduced from subgroup samples of 5 per hour to 5 per 2 hours or 1 piece per hour, based upon the stability of the constant-cause system. Sampling plans by attribute can be considered to replace sampling plans by variables, reducing sample sizes noticeably. Numerous other types of tailor-made sampling plans are modified or replaced frequently with the need.

4. Variable Control Charts ($\bar{X}$ & R) on Leading or Potential Defects

It is impossible to indiscriminately apply variable control charts in the production-engineering climate. The manpower needs are prohibitive. Therefore, attention is directed only towards quality problems, both before the fact and during the fact. Some typical problems for application of variable control charts are (a) leading defects, (b) close tolerances that can be the source of trouble (c) characteristics on components contributing to assembly difficulties, (d) past repetitive failures in meeting requirements on similar parts, (e) important physical or functional tests, (f) machine groups that have been out-of-control on a fraction defective basis, and (g) new or modified machines. Normally, $\bar{X}$ & R charts are employed, with subgroup sample sizes up to ten (10) pieces; on limited occasions, $\bar{X}$ & ∇ charts are used with subgroup sample sizes of twelve (12) to fifteen (15) pieces.

Every control chart that is placed out in the shops is originally designed by quality control on a reproducible form (Figure 18) and then turned over to process inspection, along with reproduced copies. The time-saving features by reproducing copies has been found to be most significant. Control charts are maintained by process inspection, and monitored by quality control. When the need for such charting is eliminated, the charts are immediately removed.

5. Audit Product and Process Quality Results

Complacency and rigidity of industrial operations is tantamount to industrial suicide in today's market of complex equipment. It is constantly necessary to continue to audit performance to determine past, present, and future capabilities.

From these determinations, various courses of action can be pursued, ranging from purely informational and advisory results to major changes in methodizing, manufacturing, or design.

The extent of auditing includes:

a - Weekly review and analysis of "Leading Defects"
b - Monthly review and analysis of "Shop Process and Product Quality"
c - Monthly review and analysis of process averages and sampling effectiveness
d - Monthly review of scrap dollar losses for shop and product
e - Quarterly appraisal of inspection costs compared to scrap dollar losses
f - Continuous monitoring of variable and attribute control charts maintained on quality problems or leading defects
g - Periodic appraisal of adherence to quality assurance plans and procedures
h - Analysis of outgoing product quality levels and problems
i - Appraisal of product and process quality from new processes
j - Analysis of field complaints

The results of this auditing serves as a basis for corrective action, adjustment in processing or inspection, and the realization of optimum performance.

6. Analysis of Quality Problems for Feedback to Design Engineers and Methods Engineers

A good working relationship should exist among the design engineer, methods engineer, and quality control engineer for the evaluation of product quality before

F. A. DIMENSIONAL QUALITY CONTROL

SHOP ANALYSIS CHART

AVERAGES AND RANGES

PART NUMBER C-5929678	DESCRIPTION M2A1 RANGE FINDER		
LOT NUMBER	ORDER NO. 76092-01	MACHINE NO.	DEPT. M-1 SHOP
OPERATOR	SHIFT	DATE	INSPECTOR

AVERAGES

1.767
6
1.765
4
3
2
1
1.760
9
8
7
6
5
4
3
2
1
1.750
49
1.748

U.C.L.

L.C.L.

1.761 — .008 O.D.

RANGES

.010
9
8
7
6
5
4
3
2
1
.000

U.C.L.

DIMENSION AND TOLERANCES:
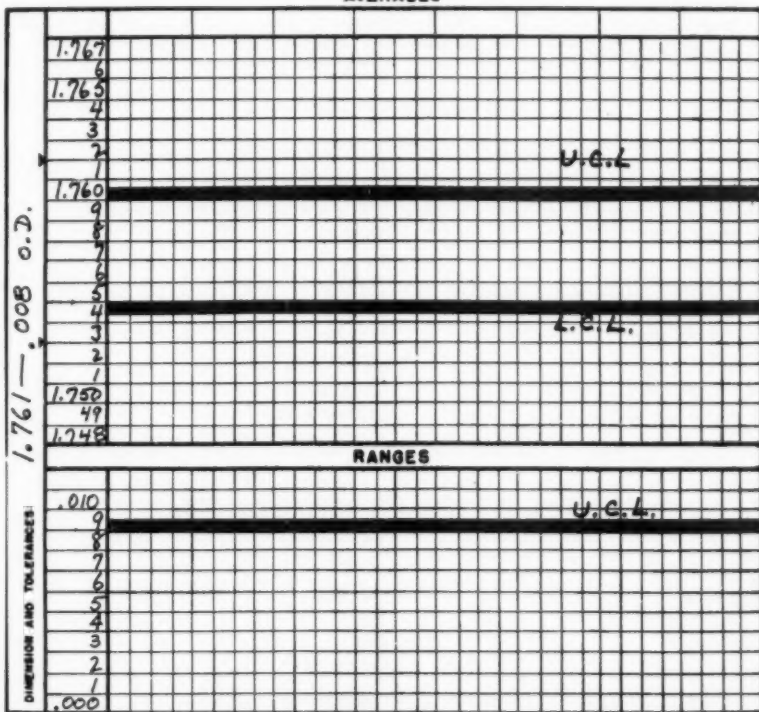
REMARKS:

$m = 5/hr.$

Fig. 18

the start of regular production, during the stages of prototype manufacture and in the course of regular manufacture.

Our quality control engineer contributes in the feedback cycle to design and methods engineers by working on the --

    a - realism of specifications,
    b - practicality of tolerances,
    c - test sample sizes,
    d - evaluation of inspection and test results,
    e - compatibility of tolerances with machining capabilities,
    f - quality control planning,
    g - design of industrial experiments,
    h - developing of a quality index or a composite picture of the final product
        quality, and
    i - application of advanced gaging.

In actuality, the contributions made by the quality control engineer are both engineering and statistical. The closer the quality control engineer remains to the new or modified design, the more effective is the prevention of quality problems. Concentrated effort devoted to the details in the early interval of the product growth prevents the utilization of much trouble shooting during manufacture.

7. <u>Analysis of Costs of Achieving and Maintaining Product and Process Quality</u>

The acid test of effectiveness most frequently used by management is the cost of operating the activity and the resultant savings. The economics of quality in the Operations Division is primarily considered from the standpoint of dollar value of scrap compared to the dollar value of production dollars expended. Comparisons are maintained and studied monthly for each of the major manufacturing shops and for each major type of production item. Actually, the comparison is expressed in terms of a percentage index (I):

$$I_\% = \frac{D}{P} \times 100$$

where

    I = % (index)
    D = accumulative dollar value of scrap material
    P = accumulative production dollars expended

Each month, the complete dollar picture is presented to management, with appropriate recommendations. From this economic appraisal, various courses of action are pursued. This might include adjustment in inspection for more effective control measures at the operation causing the significant defect, closer supervision devoted towards certain products or operations, re-evaluation of the process by methods engineering, different tooling needs, changes in material, etc. In Figure 19 can be seen the graphical portion of the "Monthly Scrap Dollar Index" report, which also includes man-hours lost in scrap compared to man-hours expended. The economics of quality losses prove to be a good, tangible score readily understood by all levels of management and supervision.

<div align="center">Conclusion</div>

There is no one best way to controlling quality in the production-engineering type of industry. On the other hand, the science and management of quality control has advanced sufficiently to offer numerous ideas and techniques for coping with particular situations. In this paper, an attempt has been made to describe a particular approach to the control of quality in an industrial climate where the planning, control and manufacturing are faced with a wide variety of low density items which range throughout all degrees of complexities. Practical quality control applications, together with theoretical techniques, have been tailor-made to meet the need.

Fig. 19

This discussion has been presented in the sincere belief that regardless of the system you employ in controlling and assuring quality, there must be integrated and systematic thinking. The increasing demands for precision in military and consumer goods necessitates that quality control people effectively design their operations.

Acknowledgment

Often when a paper is developed based upon the industrial experiences gained in a particular company, little or no credit for freedom of expression and direction is given to our company's management. The writer is grateful to Major J. T. Robinson, Chief, Operations Division; Mr. George Ripka, Deputy Chief, Operations Division; and Mr. Arthur Hewitt, Chief, Production Engineering Branch; all of the Frankford Arsenal, who were directly responsible for this opportunity. While progress comes about from inspiration and perspiration, it is a rational type of management that provides the catalyst for advancement.

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A QUANTITATIVE APPROACH TO CLASSIFICATION OF CHARACTERISTICS

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INTRODUCTION

"Quality" refers to the ability of the product to meet given specifications and comply with design drawings. "Quality of a product" should not be confused with "a quality product," the latter having a generally accepted connotation of a luxury item.

The quality of a product can be measured only in relation to its quality characteristics. By classifying the importance of each characteristic and inspecting to an adequate corresponding protection level, three substantial advantages accrue:

1. Quality is improved by affording each characteristic the proper inspection emphasis;

2. Inspection costs in relation to improved quality are reduced by de-emphasizing those characteristics of lesser importance;

3. Design is retained by the design agency. In the absence of classification of characteristics, each inspector is prone to accept or reject based on his own evaluation of the importance of the non-conforming characteristic, thereby altering the design criteria.

In most applications to costly, complex end products, characteristics are usually classified within the following definitive framework:

1. Critical - Very Serious - a departure from requirements of such a characteristic, if undetected by inspection:

   a. Could cause an operating failure of the system;

   b. Could result in reduced operating life of the system;

   c. Could cause personal injury or property damage.

2. Major - Serious - a departure from requirements of such a characteristic, if undetected by inspection:

   a. Could cause a system failure of a less serious nature (e.g., adjustment failure, operation below standard);

   b. Could cause a failure of the unit (not of the system) or reduce the usability of the unit;

   c. Could affect interchangeability and assembly operations;

   d. Could necessitate increased maintenance.

3. Minor - Not Serious - a departure from standards of such a characteristic, if undetected by inspection, although undesirable, would not appreciably interfere with the function or usability of the unit.

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THE QUESTION OF DEGREE

The above definitions are qualitative in nature. Conspicuously lacking is a quantitative guide to aid the classifier in his judgement. An obvious question from the cognizant engineer might be paraphrased as follows: "Do not many characteristics become critical if their tolerance is sufficiently exceeded?" Surely it is true that an amplifier gain specified as at least 1000 could become critical if it were only 500, but the probability of such an occurrence not being detected by inspection is very slim under usual sampling protection levels.

The problem encountered by the engineer is therefore one of degree. Naturally, if the engineer decides that a characteristic would be critical when its tolerance is exceeded, regardless of the degree, that characteristic should be classified as critical. This situation does not present a problem. However, the engineer's dilemma arises when a characteristic can be either major or critical - major when its tolerance is exceeded by less than a specific amount, critical when its tolerance is exceeded by more than that specific amount.

Prone to think in terms of safety factors, the engineer would probably classify all such characteristics as critical, thus necessitating undue inspection emphasis and cost.

ANALYTICAL DECISION BETWEEN CRITICAL AND MAJOR CLASSIFICATION

An example would best illustrate the suggested quantitative approach to the above problem. Assume the following:

1. Incoming sampling inspection in accordance with MIL-STD-105B, Level II, Normal Inspection, .65% A.Q.L.

2. 100 per cent inspection of rejected lots.

3. An average incoming lot size of 100 units (necessitating a sample size of 25 with a rejection number of 1) with the characteristic in question classified as major.

4. A drawing requirement for that characteristic of .750" with a tolerance of $\pm$ .005" (.745" to .755").

5. A normally distributed incoming lot of 100 units with this characteristic averaging .750" and varying from .7395" to .7605" - an excess of tolerance of approximately 110 per cent determined as follows:

$$[(.7605 - .755) \div .005] \ [100\%] = 110\%$$

Under this set of circumstances the lot would be 9.56 per cent defective as diagrammed in Figure 1.
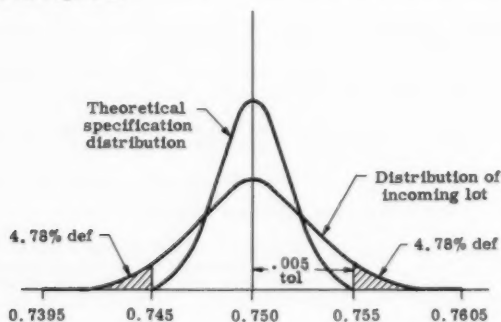
Fig. 1--Percentage Out of Tolerance

Standard deviation of incoming lot - estimated from range using 7 sigma as representative of the distribution's total spread:*

$s = .0210 \div 7$

$s = .003$

Per cent of lot within tolerance (Q_t):

$t = (.750 - .745) \div .003 = +1.667 = 45.22\%$

$t = (.750 - .755) \div .003 = -1.667 = 45.22\%$

$Q_t = 45.22\% + 45.22\% = 90.44\%$

Per cent of lot out of tolerance (P_t):

$P_t = 100.00\% - 90.44\% = 9.56\%$**

The above assumed sampling plan would, for a 9.56 per cent defective lot, yield a probability of rejection of approximately .952 as computed from the hypergeometric distribution.

Lastly, assume this .952 probability of rejection to be an adequate level of protection against accepting a critical departure from standards.

This simple analysis affords the engineer a quantitative tool to aid him in his decision between a critical and major characteristic. Applicable only to the above stated sampling plan, if the engineer decides that a characteristic would be critical only when its tolerance is exceeded by 110 per cent or more, that characteristic should be classified as major.

Thus, for this sampling plan, if the characteristic were to exceed the drawing tolerance by anything greater than 110 per cent, the lot would be greater than 9.56 per cent defective and would, with very high probability, be rejected. All critical departures would be screened in 100 per cent inspection. If the characteristic did not exceed the drawing tolerance by 110 per cent or more, it would not be critical by engineering decision and would be subject to the protection level for major characteristics provided by the sampling plan.

It must be stressed that the use of 110 per cent in excess of the tolerance should not be considered as gospel. Rather it signifies a protection level thought to be adequate. The protection level offered by each percentage excess of the tolerance varies with different sampling plans as well as for different lot sizes within the same sampling plan.

In Figures II, III and IV, Classification of Characteristics Risk Curves are given for .40%, .65% and 1.0% A.Q.L.'s respectively. Again, an example best illustrates the use of these curves. Assume a .65% A.Q.L. sampling plan in existence for major characteristics with a minimum lot size of 100 for units in question. It is desired to determine that percentage excess of tolerance that will yield a .99 probability of rejecting the lot (.01 probability of acceptance) that contains one or more critical deviations. A greater risk cannot be tolerated. From Figure III, curve F, 140 per cent is found to meet the criteria. Therefore, in classifying characteristics, the engineer should:

    1. Classify as critical those characteristics which will become critical when their tolerances are exceeded by less than 140 per cent.

* The use of 7 rather than 6 sigma to estimate the standard deviation results in a smaller estimate of the lot per cent defective and, therefore, a smaller probability of rejection. This is a conservative approach in that the probability of rejection is more likely to be underestimated than overestimated.

** The estimated per cent defective of the incoming lot is based on an equal proportion beyond each tolerance limit. If the distribution exhibited a mean shift, the per cent defective would be greater and hence the probability of rejection would be greater.

2. Classify as major those characteristics which will become critical only when their tolerances are exceeded by 140 per cent or more.

ANALYTICAL DECISION BETWEEN MAJOR AND MINOR CLASSIFICATION

When a characteristic can be either minor or major - minor when its tolerance is exceeded by less than a specific amount, major when its tolerance is exceeded by more than that specific amount - a similar dilemma confronts the engineer. Using the applicable sampling plan for minor characteristics, the approach, as before, is merely to determine a percentage excess of tolerance that will yield a per cent defective corresponding to the desired probability of rejecting a lot that contains one or more major deviations. Having determined this corresponding percentage excess of tolerance, the engineer would:

1. Classify as major those characteristics which will become major when their tolerances are exceeded by less than that determined percentage.

2. Classify as minor those characteristics which will become major only when their tolerances are exceeded by that determined percentage or more.

In Figure V, Classification of Characteristics Risk Curves are given for a 4.0% A.Q.L. which is very common sampling level for minor characteristics.

CONCLUSION

What has been done in this paper can be summarized very simply. Per cent defective has been converted to percentage excess of tolerance, thereby converting operating characteristics curves to classification of characteristics risk curves.

To the authors' knowledge little, if anything, has ever been published on a statistical approach to classification of characteristics. The need exists for such an approach especially if industry is to realistically meet the increasing military requirements for classification of characteristics.

Granted, there are many uncontrollable factors such as differing engineering opinions, differing lot distributions and varying costs to mention the more important ones. Nevertheless, this technique provides estimates that are adequate for their purposes.

END

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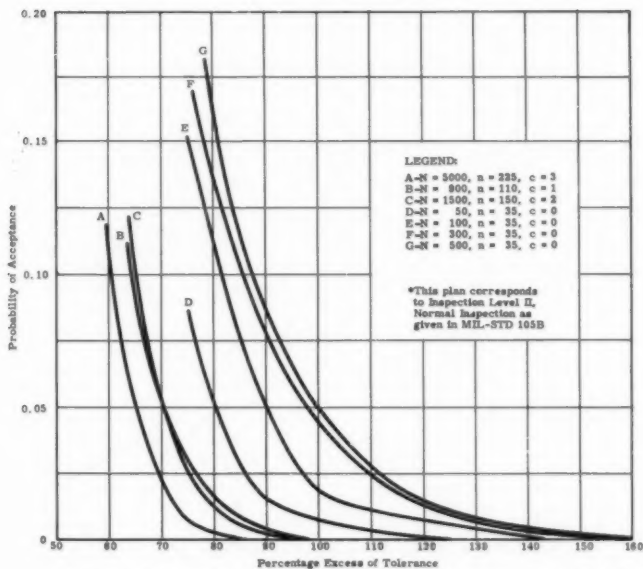
Fig. II--Classification of Characteristics Risk Curves, 0.40% AQL*
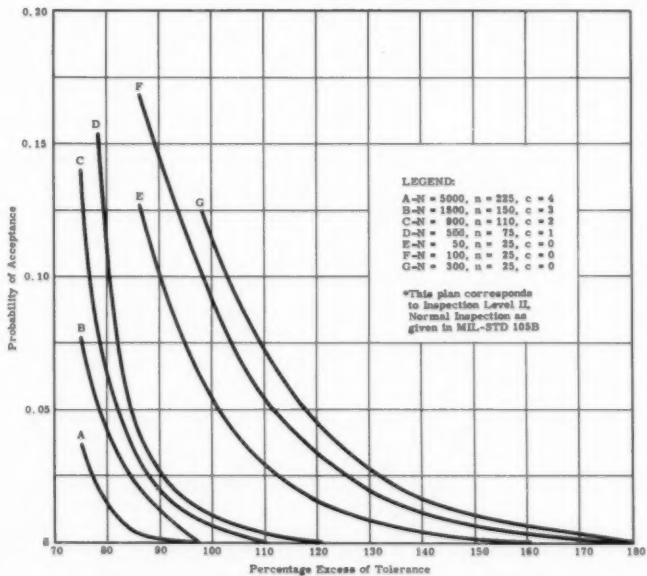
Fig. III--Classification of Characteristics Risk Curves, 0.65% AQL*
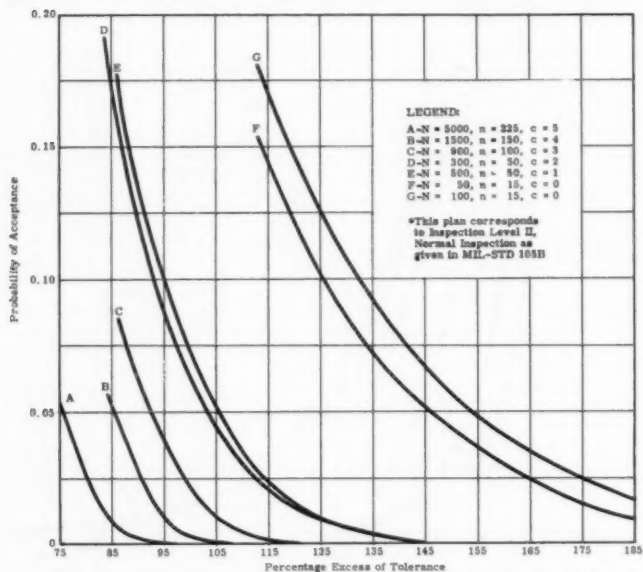
Fig. IV--Classification of Characteristics Risk Curves, 1.0% AQL*
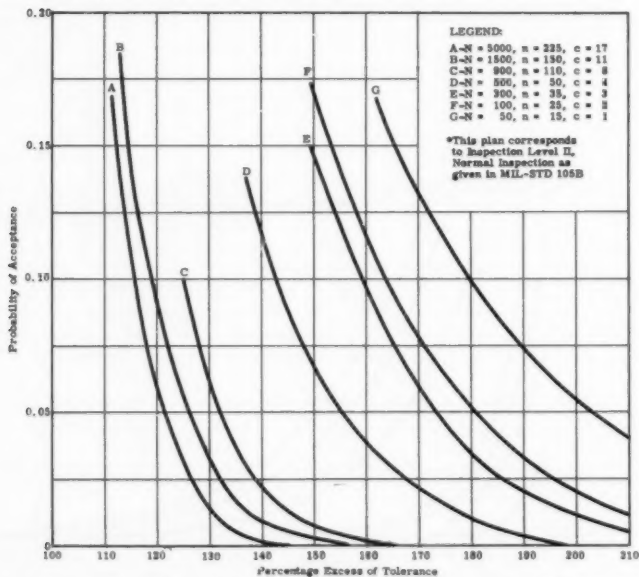
Fig. V--Classification of Characteristics Risk Curves, 4.0% AQL*

SUBJECTIVE PRODUCT EVALUATION METHODS

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Throughout the various phases of developing and processing food products, there is as much need for frequent evaluations of taste as there is for physical and chemical measurements. Even in the early stages of development, the food researcher must answer or obtain answers to questions such as "What happens to flavor with temperature increases?", or "What are the differences among a group of experimental formulations?", or "Which formula does the consumer prefer?" These and many other related questions are asked in each succeeding step of producing foods. They will fall into two general categories, one pertaining to difference measurements and the other to preference measurements, and will apply to new product development, product improvement, cost reduction problems, and quality control problems.

Let us first examine difference measurements.

Among many techniques available for determining whether two or more samples differ from each other in one or more ways, there is one known as multiple choice tests. These tests consist of asking judges to identify or group samples into classes, e.g., judges may be told that among six samples, three are alike and three are different. They are then asked to separate the samples into two groups of three. A variation of this would be presenting five samples to judges, instructing them that four are alike and one is different and asking them to identify the different sample. In each case, the probability of grouping or identifying correctly by pure guess is readily calculated (1/10 for the first example, 1/5 for the second). If the difference among samples is real, or if the judges have an ability beyond a mere guess, then the proportion of correct answers will be significantly greater than the chance probability. A notable example of this type of test is the test variously known as the triangle, odd sample, triad, delta, or trio test. It consists of presenting a set of three coded samples to a panel of judges in which two of the samples are duplicates and one is different. Judges are informed that two are identical and one is different, and they are asked to identify the different one. If the number of correct identifications is significantly greater than chance, it is concluded that the two samples are different. Known sources of bias, e.g., code and cup position, are reduced, in the first case, by random selection of code letters and, in the second case, by presenting cups in all possible positions an equal number of times.

This type of test has the advantages that it

1. is easy to administer;
2. requires a minimum of training of judges;
3. causes minimum concern regarding taste fatigue or adaptation;
4. lends itself to simple, clear-cut statistical analysis.

Some of the shortcomings of the triangle test are:

1. The chance expectancy level is relatively high, i.e., one of three successes can be due to chance.
2. The relationship of a group of samples to some standard in terms of magnitude of difference cannot be established.
3. No information can be obtained on how samples differ, e.g., "Is coffee A more sour than B?" or "Does orange juice A have a higher flavor intensity than B?"

A very efficient way in which to conduct and analyze triangle tests is by the use of a sequential sampling plan. These plans are efficient from both the operational and statistical points of view. We are presently using a plan wherein judgments are obtained in blocks of twelve and are run to a maximum of sixty judgments. A block consisting of twelve judgments allows for complete balancing of all six possible positions in which samples may appear.

The results of each block of judgments are examined for significance and one of the following conclusions is reached:

1. The samples do not differ;
2. The samples do differ;
3. Additional information is needed.

In the first two cases, testing is stopped, while in the third, another block of twelve judgments must be obtained.

Two testing situations, each involving two types of error, are set up in this plan, and a reasonable number of judgments is obtained for meaningful results. Type I (or α) error is defined as the risk of saying there is a difference where none exists, while type II (or β) is the risk of failing to find a difference where one does exist.

In the first situation, which is applicable to quality control problems, we are interested in a small type I error and can afford to have a somewhat larger type II error. The second situation is applicable to product improvement or development problems. Here we are usually interested in a small type II error and are willing to have a slightly larger type I error. In other words, we want to take a small risk of failing to find differences where they exist. If wrong answers should be obtained by finding a difference where none exists, we merely put ourselves into the relatively harmless position of running additional, yet unnecessary, tests.

Another test of the multiple choice class is the duo-trio.

Briefly, the duo-trio consists of giving a labelled control to the judge and then presenting two "samples" under code, one of which is the control and the other the test sample. The judge is asked to indicate which sample matches the control. The test sample and the coded control are given in random order successively, and tasting is timed. This test is less efficient statistically than a triangle test because the chance expectancy is greater, i.e., 1/2 instead of 1/3. However, for some types of products it can be more effective than a triangle test. For example, in whiskey testing, where carry-over of flavor and taste fatigue are apt to be a problem, control of the time interval will help to reduce these biases. Also, the test is a more simple one from a psychological point of view since the judge is presented with only two unknowns rather than three as in the triangle test.

Another category of difference testing is the ranking test. This type of test works well where unidimensional differences are being tested. Suppose there are five sugar solutions of concentrations X_1, X_2, X_3, X_4, and X_5. These concentrations are set up to form a geometric progression. The reason for this is that taste supposedly is linearly related to concentration on a percentage scale. Five coded samples are presented to a panel of judges, each of whom ranks them in what he thinks is the increasing order of concentration. Alternatively, if the concentration X_1, X_2, X_4 and X_5 are known, a fifth sample of an intensity believed to be between X_2 and X_4 is presented, and the judges are asked to rank this unknown among the known concentrations.

The greatest disadvantage of this test is its limited application, particularly in the food field. Most of the time situations are not such that single dimensional differences occur. In a complex such as vanilla instant pudding, if formulation changes are being made where sugar level is the variable, characteristics other than sweetness may influence the taster. There may be texture differences, or the aromatics may appear less or more intense, in addition to differences in the basic taste of sweetness.

Another test that is very useful in measuring unidimensional differences among samples is the paired comparison test. This test consists of presenting a series of paired coded samples to the judge and asking him to indicate the relative concentrations of the variable in each pair. The order of presentation of samples is random. An application of this technique can be found in a paper by J.E. Sinsheimer (1).

The advantage of this test is its psychological simplicity. The judge is asked to make a decision on only two samples and is given specific information as to how the samples differ. This, like the rank test, has the disadvantage of limited use, particularly in food testing, where the rule is testing samples of a complex rather than a simple nature.

The multiple choice tests, ranking tests, and paired comparison tests give information on whether samples differ from each other without regard to the magnitude

of difference. Sometimes it is important to obtain this type of information. For example, samples differing in intensity of flavor level may be submitted for determining the degree of difference among them. The test known as "difference-from-control" can be used in this case.

The difference-from-control test consists in giving the judge a labelled control and coded test samples and asking him to indicate the degree of difference from the labelled control by use of a rating scale ranging from "identical with control" to "very different from control". The number of steps on the scale is not standard. However, 5-10 gradations are most frequently used. Less than five steps tend to be too coarse to show relative differences, particularly where small differences exist among samples, and more than 10 steps tend to confuse the judges.

It is useful to include a blind control in this test since it acts as an internal check of judge consistency. It also gives practical meaning to the mean scores assigned to the test samples. For example, if the blind control should receive a mean score of 2.0 on a 10 point scale, only samples whose ratings differ from 2.0 are considered as distinguishable from the control.

Generally, a total of five samples is a good number to be presented to a judge. More than this would dilute the results because of physiological or psychological fatigue.

There are certain difficulties, however, associated with using rating scales. It is difficult to obtain a reliable mean score since the judges will not necessarily interpret the scale in the same fashion. That is, the difference between two samples may be termed "slight" by one judge and "moderate" or "large" by another. It has also been my observation that individuals tend to fall into a pattern of using a certain part of the scale during several weeks of testing different types of products or the same type of product, regardless of the range of differences presented to them. This phenomenon may have something to do with the personality of the judge. Shy or conservative people may hesitate to rate samples "very different", while a strong-minded or dogmatic type may always use this category.

There is another difficulty associated with this test, namely, that the rating scale is a unidimensional measurement that does not indicate direction. Let us suppose that three experimental coffees differ from the control as follows:

1. Sample A is moderately different from control on the basis of less bitterness.
2. Sample B is moderately different from control on the basis of more bitterness.
3. Sample C is moderately different from control on the basis of less sourness.

Assume that the panel is adequately scoring the sample in terms of magnitude of overall difference, i.e., A, B, and C are moderately different from the control. We have no way of differentiating among the three samples because they all received a mean score reflecting moderate difference. However, they are, in fact, different in different ways. Therefore, a conclusion that all three are moderately different from the control might lead one to erroneously believe that they are probably similar to each other.

There are also tests for screening and rating judges.

For general information on judge taste acuity, there is no specific type of test that will do the job better than any other. All of the tests discussed here for testing samples can be used for testing judges. As a matter of fact the testing of judges and samples can be done concurrently. One example where this has worked well in practice is the triangle test (2). The analysis of judge ability is based on the proportion of correct identification in the test. The judge who misses on an easy test is penalized more than one who misses on a more difficult test. Conversely, the judge who identifies correctly on an easy test receives less of a score than one who identifies correctly on a more difficult test. The scores are standardized to take into account the number of tests in which a judge participates. Thus, a judge can be evaluated on a relative basis regardless of the type or number of tests in which he participates.

A similar situation can be worked out for difference-from-control tests, ranking tests, paired comparison tests, and others mentioned above.

In specific cases, where it is of interest to the taste ability of a panel for a particular product or situation, it is suggested that that test method be selected which best suits the situation, it is suggested.

For example, if the primary interest is in testing simple properties, such as bitterness or sweetness, then the rank or paired comparison test would be preferable to the triangle. However, if the product happens to be coffee or some other complex, the triangle would probably be more useful because it would be difficult, if not impossible, to instruct judges on the specific difference which they are expected to evaluate.

A classical test method for evaluating judges is the threshold test. This is usually not used in product testing. It was designed primarily to obtain information on physiological sensitivity to a given substance. Generally, such tests are run on the four basic tastes, namely, salt, sweet, sour, and bitter, to determine at what level an individual or a group is able to detect and identify the stimuli. This test has limited practical application, particularly in food testing, since most products are made up of components which are in the super threshold range and there is no clear-cut relationship on judges' ability in the threshold vs. the super threshold range. It has been my experience that there are judges who differ appreciably in their thresholds to "bitter" but are about the same when evaluating coffee containing a fair amount of bitterness.

All of the tests discussed thus far are useful in determining whether or not two or more samples differ on an overall basis or in some specific, known characteristic. However, they do not answer how samples differ in many unspecified characteristics. For example, processing studies comprising different treatments (temperature, pressure, etc.) may produce multi-dimensional flavor differences in samples which are not predictable by the experimenter. A technique available for obtaining this type of information is called "flavor profiling".

The flavor profile is a semi-quantitative method wherein differences between samples can be judged on the basis of intensity of individual character notes, order of appearance of the notes, aftertastes, mouthfeelings, blend, and body. Samples may be found different in all or some of these factors. This method is as follows:

The panel evaluates each sample in terms of the above mentioned characteristics. Each judge gives his results verbally to a panel moderator. A group discussion of the results then takes place. If any major disagreements are found, the panel meets at another session to resolve the differences.

The following is an example of two coffees which are shown to be different by profiling:

| Coffee A | | Coffee B | |
| Aroma | | Aroma | |
Character Notes	Intensities	Character Notes	Intensities
burnt (bean + cereal)	2	charred cereal	1-2
coffee fragrance	1-2	pyridine	1
burnt (caramel and vanillin)	1-2	heavy sweet	1
sour	1		

| Flavor-by-mouth | | Flavor-by-mouth | |
Character Notes	Intensities	Character Notes	Intensities
sour	1-2	sour (unclean)	2-3
burnt (cereal)	2	charred cereal	1-2
bitter	1-2	bitter	2
coffee fragrance (old boiled)	1	astringent	2
burnt caramel	1		

Intensity Scale
3-strong
2-moderate
1-slight
X-barely perceptible
0-none

It is fairly obvious that Coffee A differs from B in character notes, quality of these notes, and intensities. Coffee A has a coffee fragrance note in both aroma and flavor which is not found in B. Coffee B has a pyridine note in aroma not found in Coffee A. Coffee B is described as having a charred cereal note, whereas A has a burnt bean + cereal complex. Coffee B is astringent, whereas A is not. Coffee B is

more bitter than A.

Panels applying this technique must be thoroughly trained in the broad aspects of flavor perception. For training, a group of five to seven people who have normal abilities to taste and smell and high interest undergo a short period of indoctrination in the fundamentals of flavor perception. They learn something of the physiology of taste and smell and of the relationship of chemical and physical factors to flavor, a relationship which unfortunately is not clear-cut. Through group discussions and by use of physical reference standards, they learn something of the techniques for evaluating different types of products and the importance of developing a common and meaningful vocabulary for describing what they perceive. After this initial indoctrination, the group spends some time applying the basic principles to carefully selected practice samples.

In speaking about the qualifications of such a panel, I mentioned normal ability to taste and smell and high interest. Most people have normal physiological ability. However, interest is something else. The necessity for interest cannot be over-emphasized. In my experience, it is a major factor in the success or failure of this type of panel operation and takes equal place with panel training.

Some of the advantages of the flavor profile method are:

1. Multi-dimensional differences in samples can be described in terms of qualitative and quantitative scores.
2. The results can supply direction to the experimenter in improving his product, e.g., if roasting time or temperature studies are being conducted on coffee, the panel can select those samples which have the roast character desired by describing the individual characteristics in terms of some standard. In accelerated storage studies, it is often difficult to determine gradual staling or deterioration in a product, unless these results are given in terms of specific descriptive differences rather than overall differences.

Some of the disadvantages to this method are:

1. Initially it is expensive because of the amount of training time involved before the panel can be used in an actual work situation.
2. The results do not lend themselves well to statistical analysis or design.
3. The personalities of panel members or panel moderator might have an influence on the final results of how samples differ.

We have been discussing test methods which are very effective means for evaluating differences (both overall and specific) among samples. Up to this point, however, we have no information regarding the public's reaction to our new or improved products. Since laboratory personnel are examining products in a detached and scientific manner and since they are more or less trained to evaluate food products, they are not likely to reflect the preferences of the consuming public. Therefore, preference tests are conducted in which the consumers are the judges. The type of test most frequently run to obtain preference opinions is a home-use test. Basically, this test usually involves sending samples to a fairly large number of families (100 or more) and asking each family member to taste the samples either side-by-side or individually at different meals and to express a preference or no preference. There are many variations in this type of testing. Samples can be placed by mail or personally; various types of questionnaires can be designed for the particular information required; opinions on sample preparation may be obtained from the housewife; children's preferences can be examined separately from adults; and testing can be repeated over an extended period to determine consistency in consumer opinions or wearability of product. The advantages of testing products in the home are quite obvious. The products are being evaluated under fairly realistic conditions, the housewife has an opportunity to evaluate the product from the preparation and taste standpoints, and opinions can be gathered from all family members.

Most companies use the services of the various opinion research, market research, or advertising agencies for obtaining this type of consumer judgemnt.

Sometimes it is desirable to obtain consumer opinions on samples before they have reached the point of completion in terms of recipe tolerance. A home-use test would not be feasible under the circumstances since one can hardly present samples to the consumer which are prepared by pipetting a few milliliter of a flavor into product base. There is a method available for obtaining opinions from the consumer on in-

complete products. Booths can be set up in an area with fairly heavy traffic, such as department stores or supermarkets, where samples can be prepared by interviewers and handed out to shoppers. Most often, two coded samples are presented to the participant and he is asked whether he has a preference or no preference. Sometimes participants are asked to comment on why they preferred one sample to another.

It is realized that the individuals who are testing are not necessarily a good sample of the population about which generalizations are to be made. Since it is only preliminary testing, this lack of representation does not entail too great a risk.

Because of the increasing interest on the part of food companies toward marketing brand-new items which have no counterpart in a homemade recipe, there has arisen the need for more detailed information than is normally obtained in a home-use test or an on-the-spot preference test in a department store. A considerable amount of time has been devoted to interviewing homemakers in detail about their attitude toward the concept of a product as well as how much they liked the specific samples presented to them.

One such way of conducting this type of test is called the round-table method. A group of five to ten homemakers are usually handled at a session. They are presented with one, two, or more samples of a product, asked to examine them on the basis of flavor, texture, visual characteristics, etc., and to fill out a ballot expressing their opinions. A moderator then asks each participant to express her opinions of the samples she evaluated and to make any other comments that she might like to express. Often, these round-table tests are conducted subsequent to a home-use test, i.e., the round-table participants were also members of the home-use test panel. At times, much useful information can be gathered from this interview method, which would not show up in answers to questionnaires sent through the mail. A very efficient way of recording the discussions and conclusions of a round-table group is by means of a tape recorder. The moderator can conduct the session comfortably and efficiently without being concerned that important points have been overlooked in her own notes or those of a stenographer.

Despite the numerous and diversified schemes available for measuring difference and preference, there is still much to be done in the field of subjective evaluation methods both from the point of view of improving current methods and developing new methods. One area of investigation that might prove fruitful is learning more about human response; this will subsequently lead to better interpretation of test results.

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PUTTING THE SENSES TO WORK IN QUALITY CONTROL

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Measurement is one of the foundations on which modern quality control rests. Conditions for the optimum quality control situation can exist only when a product characteristic can be defined in a manner which precludes any possibility of misinterpretation. Where this is attained, both buyer and seller have complete assurance that their respective interests can be protected beyond any shadow of a doubt. Unfortunately, however, there are too many cases where this goal has not yet been attained. In some, the test method is imperfect, in others the quality characteristic involved is not capable of being reduced to measurable or numerical values. It is with the problems associated with the latter area that this paper will deal.

SPECIFYING QUALITY AND SETTING THE STANDARDS

Before standards can be set up for any product characteristic, there must be agreement between buyer and seller as to exactly what is desired or needed. In other words, the goal must be defined. This, of course, is true for all characteristics, and not merely the non-measurable class being considered here. Standards for measurable quality characteristics are capable of being specified and defined in written terms - both the test method and results which are to be obtained to meet quality requirements. Unfortunately this is impossible in the case of non-measurable characteristics. The only successful method by which adequate standards may be specified for this class is to set up a standard sample to which questionable products may be compared. Unless this is done, the standard can exist only in people's memory or in their interpretation of written description. Interpretation obviously is subject to many shades according to the conscious or subconscious needs and caprices of the individual concerned.

But it is also essential that the standard sample be supplemented with a written description standard. This description, in effect, defines the characteristic, while the sample is the measurement of that characteristic. Needless to say, the conditions under which the sample is to be compared - i.e., the test method, must also be defined.

A further step which is all too seldom taken, but one which is obviously desirable, is to set up tolerance standards. One of these standards will represent the quality level that is desired - the optimum; while the other represents the level below which the product is not acceptable. In some cases this range of tolerance may be quite narrow. In others it may be broad enough to make it worthwhile to justify a third sample which would represent, say, the average quality desired in a lot or shipment with the others being the maximum - minimum levels for individual units. Additional samples can also be added to the standards to represent other specific levels of quality.

The purpose of such tolerance standards is, of course, to help minimize the problem of decision in cases of marginal product quality. Daily cases will be found in every plant where a product or lot is very close to the standard - so close as to give the inspector fits as to whether to accept it or reject it. These tolerance standards do not eliminate this border-line problems, but they do help the inspector decide how far he can go.

Only a short step beyond the setting of tolerance standards is the establishment of rating procedures. Such procedures require a series of from four to five standards representing quality classifications ranging from very poor to excellent. The maximum number is set at five because the human being cannot normally classify sensory reactions consistently into more than five grades.

Rating methods will not be discussed here except to note that they provide a means for graduating quality beyond a "pass-or-reject" classification. They are designed to grade product quality along a continuous scale so as to indicate trends of quality above or below the reject point. Such procedures are essential if non-measurable quality conditions are to be included

in any well developed quality index system.

Before leaving the matter of standard samples, a brief discussion of their selection may be helpful. If only one standard is to be used, the procedure for selection is simple; the parties negotiate between themselves in determining what shall be considered acceptable from a group of samples representing various quality levels.

Where two or more tolerance standards are to be selected, a different procedure must be followed. For the problem here is not merely one of drawing a line between good and bad, but rather a problem of selecting samples to represent each of the quality levels agreed upon. The samples are, of course, selected by the interested parties - by Production and Sales, by Engineering and the customer, etc. Usually the Quality Control Department will participate as technical advisor. A proven way of selecting such standards is to arrange in random order a group of samples which represent a range of quality of the characteristic in question. Then each party chooses samples which he feels possess the correct quality for each agreed upon point in the tolerance range. Needless to say, it will be rare that two or more parties will agree at this point. Therefore, the next step is to arrange the samples again, this time in ascending order of quality. The individuals concerned will then be able to visualize the quality range of the characteristic, and will thus be in a position to negotiate in the final selection of mutually agreeable standards. The method for the selection of samples for use in an attributes rating program will follow the same procedure outlined above.

These standards, once approved, should be accurately duplicated and the resulting samples which could be called "reference standards" forwarded to all parties or departments that will be concerned with quality assurance. For example reference samples in the manufacturing and inspection areas of a plant are of inestimable value in providing answers, to say nothing of settling arguments, on quality standards as soon as they occur. Needless to say extreme care must be taken to protect the reference samples from deterioration through exposure and use. A formal system should be developed for periodically checking them against the approved master sample, which, of course, is kept under lock and key!

ADMINISTERING THE CONTROL PROGRAM

Once meaningful and realistic standards have been established for non-numerical quality characteristics, the administrative problems of assuring conformance to specifications are those typical of Attributes Inspection as distinct from the administration of Variables Inspection. Inspection by Attributes, of course, is defined as inspection wherein a unit of product is classified as simply defective or non-defective with respect to a given requirement or set of requirements. Variables Inspection, on the other hand, takes into account the degree of conformance or non-conformance of the unit by measuring the unit of product along a continuous numerical scale and by describing its quality in terms of its position along that scale.

There is, however, one distinct difference between administering the quality assurance of non-numerical quality characteristics inspected through the attributes inspection technique and administering assurance of measurable characteristics. That difference is the greater emphasis that must be placed on the proper selection and training, and on the quality and closeness of supervision of personnel who are responsible for evaluating and making decisions on non-measurable quality characteristics. While this difference is mainly one of degree, it is nevertheless of fundamental importance. The distinction, of course, is caused by the dual role that the inspector must play simultaneously as testing instrument and judge. For as has been pointed out earlier, the evaluation of conformance to established standards is necessarily to a great degree subjective and interpretive. And regardless of how carefully standard samples have been selected, disagreement of interpretation as to the degree of a product's conformance to standard will still rear its ugly head in marginal cases.

1. Selection and Training of Personnel

As in all problems of assurance of quality conformance, the sine qua non selection of inspectors having appropriate aptitudes for the job, followed by education, training and on-the-job supervision. In the case of quality assurance of non-numerical characteristics, however, certain traits are particularly critical due to the fact that the inspectors must judge conformance

subjectively through their senses rather than with physical, chemical or electrical measuring instruments or gauges. The Quality Control supervisor, when he hires personnel for this type of work, is in reality employing in one person both an inspector and a measuring instrument - namely, his sense of touch, color discrimination, sense of smell, etc. We will not concern ourselves here with a general discussion of what one should look for in a candidate for an inspector's position, such as integrity, intelligence and appropriate physical aptitudes. It might be well, though, to discuss briefly some of the special attributes that inspectors of non-numerical characteristics must possess.

First, personnel must be selected who have not only the necessary aptitudes for performing the test method to begin with, but also the required acuteness of the sensory organs which will in effect be the testing instruments. Inspectors can, of course, be tested and screened for this aptitude. Second, candidates must possess the intelligence and judgement necessary to enable them to translate effectively and consistently what their senses tell them into decisions as to conformance or non-conformance to the standards. Screening applicants for this trait is slightly more difficult, and chances of errors in the screening process far greater. Third, they must possess evenness of temperament so that outside, or inside, pressures will not affect their judgement - or to put it another way, throw their senses out of kilter. It is one thing to require a temperament that will make a man decisive and not falter when he has a gauge to back him up; it is quite another when he must defend and control his conviction that he is in control of his senses! This quality is essential to minimize the effect of a "bad day" on an inspector's judgement, to say nothing of the effect of his reaction to the pressures of irate operators whose work he is inspecting or to the many other pressures of production. It is all too easy for him to let his "measuring instrument" get out of "calibration" in such cases. And it requires a keen supervisor to know when an inspector is yielding to such pressures. This quality is difficult to predict in an applicant, but adequate supervision will quickly detect it on the production floor.

Having selected personnel possessing the above essential traits, and having indoctrinated them into company, departmental and job routines, the next step is to train them in the use of their senses by exposing them to all the shades of variations in product quality - to calibrate them, so to speak. But this alone is not enough. For even though their senses have been developed to the point where they can compare products with the standard correctly, it is further essential to train them in such a way as to minimize the danger of "drift". This latter phenomenon is a well-known problem in this area of quality control, but will be defined in detail later.

Perhaps the best way to avoid drift is to make sure that every inspector understands the importance of his decisions from the viewpoints of not only outgoing quality but also of the costs and delays caused by rework and scrap. This sounds trite and obvious, but I state it here because, although such education is of basic importance in the training of any spector, it is especially essential for inspectors responsible for assurance of non-measurable quality. Orientation in this area can be of inestimable aid in helping them "stick to their guns" when the going gets rough. Not only is such initial training necessary, but also continual follow up through reorientation conferences is vital to say nothing of their being called in on the details of quality complaints. Exposure to customer complaints will not only help maintain in them this critical feeling of responsibility, but also it will help give inspectors an added "feel" for their job and will tune their senses more keenly to their task.

2. Administrative Problems

As in the case of personnel selection the administration of the quality assurance activity involving non-measurable characteristics is similar to most quality assurance programs. There are, however, certain problems peculiar to our case. Again we will consider the problem from the standpoint of the floor inspectors and the quality laboratory, but the points brought out here apply equally to all phases of administration. One of the problems that is often difficult to detect is the natural tendency for an inspector's judgement, or even that of one entire department, to drift either toward an excessively tight interpretation or, conversely, towards a lax interpretation of the standards in the case of marginal products. This problem will be minimized but not completely eliminated by the use of tolerance standards as was discussed earlier. Some, from over-zealousness, will tend to tighten up their interpretation and demand perfection; others because of sympathy, say, for a production departments' quality dilemma, will stray towards laxity. This natural tendency will be accentuated one way or the other by organizational indepen-

dence of the quality control department on the one hand or by domination of it by production on the other. But in any event it is an ever-present danger, the existance of which higher management must be continually aware. One answer to this problem is a periodic "audit" of the inspector's judgement by properly oriented individuals, whose duty it is to assess the inspector's decision of border-line cases. Another solution is to check an inspector's judgement by having him pass on samples which have been previously compared and rated against the standards. Reorienting the inspector will then be a relatively easy matter.

One of the more insidious problems that may arise in administering such a program is the effect on an inspector's morale if his decision on border-line cases is countermanded. This may happen from time to time for a variety of reasons - either because the chief inspector may disagree with him or because the sales department may decide that quality may be more lax for a certain customer, etc. In any case, the effect on the inspector's morale may cause him permanently to shift his interpretation of questionable cases. This is not so true with measurable characteristics where it is possible to waive products failing the standard by a certain fraction or percentage. But how does one define the degree to which the quality of a non-numerical characteristic may fail to match the minimum standard and still be waived? The only answer, of course, is to set up a new standard for each such case. Failing that, extreme care must be taken to explain to the inspector why his judgement has been overruled. Here, again, is an example which shows the rewards of orienting the inspectors to customers' needs and complaints. The better an inspector understands why he is asked to vary his interpretation of what he can accept in such special cases, the less likely it is that he will become discouraged or let his judgement drift.

The relationships between inspectors and production operators is another tricky problem, where through the inspector's authority to accept or reject work he in effect has a hand in writing an operator's pay check where the operator is paid only for good work produced. This, of course, is merely an on-the-firing-line extension of the problems of relationship between quality control supervision and production supervision. Once again the point at issue is the subjectivity of quality decision. One can easily imagine the pressures imposed on inspectors by irate operators who will be so penalized for rejected material. Obviously one of quality control supervision's most important administrative jobs is to orient production supervision and in turn help them indoctrinate line operators in the necessity of accepting the quality control department's decision. And it requires the understanding and active support of higher management to maintain quality control's authority and prestige by backing their decisions and educating production in this area.

SUMMARY

Control of the quality of non-numerical product characteristics, then, differs from the control of measurable characteristics in that greater reliance must be placed on the individual-on his ability to evaluate quality conformance accurately and consistently-for it is necessary to rely completely on his senses and on his translation of what his senses tell him into quality decisions.

Through the use of intelligent screening and, even more important, through close attention to supervision of both inspection and production personnel, however, perfectly satisfactory results should be attained. Nevertheless, the subjectivity of the quality evaluation method, is a basic weakness and this technique of quality control should be replaced by the use of numerical standards wherever it is possible and economically feasible to do so.

STATISTICAL AIDS TO VISUAL INSPECTION

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This paper discusses some of the statistical methods that are available to the quality control engineer for use in evaluating and increasing the efficiency or effectiveness of visual inspection.

SAMPLING PLANS

Sampling plans, when applied to inspection done in the plant between processing operations, provide an effective means of reducing inspection costs and improving quality. When applied to visual inspection areas, they have the added advantage of reducing inspection fatigue, especially that associated with highly polished parts. As a result, better quality is passed with fewer scrap or salvage pieces.

Inspection Procedures

Die cast parts, after polishing, are assembled by the polisher into lots of various sizes on carts especially designed for that purpose. A typical cart is shown in Figure I with the part shown in Figure 2. If the part is produced on an automatic polishing machine, the unloader assembles the parts into lots. These parts are then randomly sampled by an inspector. Random sampling is assured by having the inspector use a deck of numbered cards that are thoroughly shuffled before drawing cards. The first card drawn designates the column that the part is to be selected from with the second card designating the row.

A rejected lot is sorted 100 per cent by the polisher, the "bad" parts are re-polished or scrapped, and the lot is resubmitted to the inspector for resampling.

The selection of the inspectors and the inspection standard is of utmost importance in any visual inspection scheme. We are not gaging a part or classifying it by go, no-go gages, but are visually inspecting it. Human judgment thus plays a very important role.

The quality standards used must be carefully chosen by top level inspection personnel. These standards are then prominently displayed where the inspector has ready access to them and are used as a basis for acceptance or rejection decisions.

However, the competence of the inspector, who samples and checks the parts, remains the dominating factor. This inspector must be conscientious, work with a minimum amount of supervision, and have consistency, or repeatability, of decisions. It is essential that he continue, based on the quality standard, to call a good part good and a bad part bad. To assure this, we have had the sampling inspectors rank ten carefully chosen parts in order of the degree of defectiveness. The repeatability of the inspectors' judgement has been excellent. The majority of the inspectors have worked on visual inspection assignments for a minimum of ten years. We have noted, however, in 100 per cent inspection areas, that the repeatability of decisions is comparatively poor. A part of X quality will pass an inspection station in the morning and be rejected in the afternoon, or vice versa. Also in 100 per cent inspection areas a gradual deterioration in quality will often not be noticed until a drastic change in quality level has taken place. We have not observed these phenomena in sampling areas.

Plans Used

AOQL plans were chosen because it is essential that the parts leaving our pol-
ishing department, in the long run, be of quality better than or equal to the AOQL.
The quality of the plated part is directly dependent upon the quality of the polished
part.

The AOQL ranges that we have found practical run from 1 to 4 per cent.   The
chosen AOQL is dependent upon:

    (1) the budgeted scrap allowance, based upon scrap costs
    (2) the difficulty of polishing and plating the part; and
    (3) the end quality desired in the part.

A typical sampling table used by the floor inspector is shown in Table I.   The
p'_m values represent approximate incoming lot quality corresponding to the AOQL value
on the AOQ curve for the plan. Values of the AOQL corresponding to p'_m can be com-
puted from tables of the Maximum values of (pa) (p'N) from given values of c in acc-
ordance with the formula
    AOQL= (pa) (P' N) where p' is of course the fraction defective of the incoming
lot that gives the AOQL.
    i.e.   for the plan N = 35, c = 1
           max (pa) (p'N) = .8408
           AOQL = $\frac{.8408}{35}$ = .024 = 2.4%

TABLE I -- Sampling Table

Part	Sample Size	Reject Number	AOQL (%)	p'_m (%)
A	35	2	2.4	5
B	35	2	2.4	5
C	25	1	1.5	4
D	18	1	1.0	6
E	75	4	2.6	4

Advantages Of Sampling Plans

The use of sampling plans instead of 100 per cent inspection has the following
advantages:

    1. Inspection efficiency is increased
    2. The amount of inspection labor is decreased
    3. The quality level increases
    4. The emphasis on quality is placed upon production
    5. Rework and scrap are decreased

As the inspection efficiency is increased, fewer bad parts are sent to the next
process and, as a result, better quality parts with less scrap emerge from the total
process. An inspector, after looking at 1000 or more parts that are highly polished,
becomes fatigued and his eyes blur over defects.

A decrease in the amount of inspection labor is a definite monetary savings
that also comes as a direct result of the use of sampling plans. The following ex-
ample will illustrate savings that we made in this area alone.

Five hundred parts per hour were being produced by four different polishing
lines, each line polishing a different part. Under 100 per cent inspection this re-
quired four inspectors. These parts, however, are now placed in specially designed
containers in lots of 500. The sampling inspector takes a maximum of 15 minutes to
sample and check the skid if it is to be accepted; less time, normally, if it is

rejected. Thus, this one inspector can now judge the same volume of product that formerly required four.

Emphasis on quality is placed upon production through the use of sampling plans. In any 100 per cent inspection scheme, the burden of maintaining the quality of the parts being inspected rests on the inspection department. As a result, the producer of the part (in this case the polisher) takes little pride in the quality of his work, for he knows that if it is not acceptable it will be sent back to him. Thus, the emphasis on quality shifts from the producer to the inspector.

Sampling plans, however, reject the work by lots if it does not appear to meet the prescribed quality level. It is now, not inspection's job to maintain a specified quality level, but production's, as the polisher responsible for a rejected lot must reinspect his work and bring it up to the quality level, either by replacing the bad parts with good ones or by repairing the bad ones. As a result, the production man can not make his quota if he has many lots rejected.

Rework and scrap are decreased because better quality parts come from the production department. When parts are being 100 per cent inspected, they are accepted by the inspection department and production flow is kept steady regardless of the quality level. However, the use of sampling plans may result in an interruption in this production flow. This condition will occur when the average quality level submitted to inspection is poorer than the AOQL. Thus, a poor quality level is forcibly brought to management's attention, and either the cause of the poor quality will be eliminated, or 100 per cent inspection must be returned to the job, at greater cost.

RANKING PROCEDURES

The ranking process is a method that enables the user to assess the agreement of two or more individuals in judging the comparitive qualities of two or more items. This is the type of act that is performed when evaluating the merits of various cuts of steaks, bottles of whiskey, sharpness of cheese, etc. It is used by us in establishing quality standards on buffed and plated parts.

The procedure used entails the selection of ten carefully chosen parts that represent the varying degrees of quality to be expected from a process. These parts, after being assigned numbers, are then ranked by the staff management members of the Quality Department. The overall correlation coefficient is computed and assuming the correlation is significant the parts are reassigned a quality rank. The quality standard is then chosen from these parts, and is of course dependent upon the customers' quality requirements. The following example will show the basic computations involved.

TABLE II

Inspector	Best			Ranked to						Worst
A	1	4	6	8	3	5	2	7	9	10
B	1	6	4	5	8	2	3	7	9	10
C	1	4	6	3	5	2	8	7	9	10
D	1	4	5	6	8	7	3	2	9	10
E	1	4	6	3	5	2	8	7	9	10
F	1	2	3	4	5	6	7	8	9	10
Totals	6	24	30	29	34	24	31	38	54	60 $\sum 330$

Compute the "Coefficient of Concordance" W

$$W = \frac{S}{S_{max.}} = \frac{\sum d^2}{\frac{m^2 (n^3 - n)}{12}}$$

where

d - difference between the observed rank total and the expected rank total assuming no difference in quality or judgement

m = number of inspectors
n = number of items

$$W = (33-6)^2 + (33-24)^2 + (33-30)^2 + \ldots\ldots$$
$$\frac{6^2 (10^3 - 10)}{12}$$

$$W = \frac{2116}{2970} = .71$$

The simplest significance testing of W is done using Snedecor's F
Compute a corrected W using

$$W = \frac{S - 1}{\frac{m^2 (n^3 - n)}{12} + 2} = \frac{2116 - 1}{2970 + 2} = \frac{2115}{2972} = .71$$

for this case there is no difference
Compute F as

$$F = \frac{(m-1) W}{1-W} = \frac{(5-1) (.71)}{1 - .71} = \frac{2.84}{.29} = 2.84$$

$$F = 9.79$$

Degrees of freedom in the numerator = $(n-1)\frac{2}{m} = 9\frac{2}{6} = 8.67$ or 9

Degrees of freedom in the denominator

$$(m-1) \left[(n-1) - \frac{2}{m} \right] = 5 \left[9\frac{2}{6} \right] = 43.4 \text{ or } 44$$

Then using the F table

5% level F = 2.10   1% level F = 2.84

As the computed value of F is larger than the tabled value at the 1% level of significance the rankers exhibit a significant degree of agreement. However had the rankers failed to agree this would have resulted in a reselection of parts. Visual inspection of the rank table shows that the judgement of the rankers was poorest where the quality of the part was "average". This is to say that it is difficult to decide on so-called "borderline" quality parts.

<div align="center">AVERAGE QUALITY LEVEL CHART</div>

The percent defective chart has long been used as a means of controlling the "goodness" or "badness" of parts upon which the characteristic checked could not be measured but only classified as good or bad. In the application of the P chart to the control of die cast quality in our plant it has not been unusual to continually run a job at 8% defective and periodically have complaints from our polishing department that the quality has decreased and upon recheck show the process still running 8% bad, but the "bad" parts have become exceptionally bad in regards to quality. That is to say the degree of defectiveness has increased and consequently it has taken more labor and material to make acceptable the defective parts.

Thus, a need was present for a more sensitive tool than the P chart. As a result of this the Average Quality Level chart was developed.

Details of Operation

The first step is to pick out, preferably by means of a visual ranking technique, the Average Quality Level part; this part is assigned the number 0. The next part selected from the process should represent the best quality obtainable and this part is assigned the number +2. The next part, whose quality level is halfway between the 0

and $\neq 2$ parts is assigned the number $\neq 1$. The worst quality part obtainable is then selected and given the number $- 2$. Finally, the part whose quality fails halfway between 0 and $- 2$ is selected and assigned the number $- 1$. We have thus selected and graded, in units of one, all the possible quality parts according to the process under PRESENT OPERATING CONDITIONS. These quality level standard parts are then retained so that all inspection personnel have ready access to these standards.

Ten random parts are then selected every two hours (this time interval is at the user's discretion) and noted as $\neq 2$, $\neq 1$, 0, $- 1$, or $- 2$ for each part. The values thus obtained are averaged, keeping the sign and the average quality level thus record-ed and plotted on the average chart.

Theory

By assigning the numbers from $- 2$ to $\neq 2$ to the five possible quality level pieces emanating from the process, we have in essence allowed ourselves to check the visual quality of the part by variables.

The upper and lower quality level control limits (UQLL & LQLL) are expressed in terms of the standard deviation of the average ($\sigma_{\overline{QL}}$).

$$UQLL = \overline{QL} \neq 3 \, \sigma_{\overline{QL}} \qquad LQLL = \overline{QL} - 3 \, \sigma_{\overline{QL}}$$

Now, the standard deviation of our parent population is 2/3, assuming that $6\,\sigma$ encom-pass 100%, not 99.7% of our values. The standard deviation of the average is $\sigma/\sqrt{n}$ which for this case equals $2/3 \div \sqrt{10}$ which equals .2108 or .211

For our case where the sample size is always 10,

$$UQLL = \overline{QL} \neq .633 \qquad LQLL = \overline{QL} - .633$$

Thus, three times the standard error of the mean is .633. Accordingly, if two points in close succession fall outside the upper or lower quality level limit, we know the population mean has changed. This means that the average quality level part or 0 part is no longer the true average quality level part but that this part should be re-selected along with the other standard parts.

The following examples in Table III will show the sensitiveness of Quality Level Chart in comparison with the P chart.

TABLE III

Example 1

Ten samples 1, 1, 0, 2, 2, -1, -1, -2, -2, -1, $\overline{QL} = -.1$
$\qquad\qquad P = 50\%$

Example 2

Ten samples 1, 1, 0, 1, 2, -1, -1, -1, -1, -1, $\overline{QL} = 0$
$\qquad\qquad P = 50\%$

Example 3

Ten samples 1, 0, -1, 0, 0, 1, -1, -1, -1, -1, $\overline{QL} = -.3$
$\qquad\qquad P = 50\%$

Example 4

Ten samples 2, 2, 1, 1, 1, -1, -1, -1, -1, -1, $\overline{QL} = \neq .2$
$\qquad\qquad P = 50\%$

In these four examples a decided shift in degree of defectiveness has occurred while the process has remained 50% defective. This technique has proved most valuable on processes producing parts where this shift occurs.

OTHER QUALITY RATING SYSTEMS USED

In addition to the Quality Level system we are using as a general control check the chart for defects per piece and to accurately assess the main difficulties or defects obtained in first run castings the critical-Major-Minor or Average Defect Point system is used. A typical check sheet for the latter method is shown in Figure 3 and is used in evaluating the quality of die castings after they have been polished.

INSPECTOR EFFECTIVENESS

The effectiveness or efficiency of the inspectors is determined using the well-known analysis of variance when comparing two or more inspectors or if comparing one inspector's results to a standard set of prior ranked parts the ranking technique can be used.

An evaluation of three inspectors checking the casting quality of a header bar was made by having the men rate, using the Quality Level system, 26 subgroups of 5 parts in each subgroup. The analysis of variance table is shown in Table IV.

TABLE IV

Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square
Between Insp.	4.33	2	2.167
Within Insp.	14.50	75	.193
Total	18.83	77	.245

$$F = \frac{\text{Between Insp. Mean Sq.}}{\text{Within Insp. Mean Sq.}} = \frac{2.167}{.193} = 11.22$$

Table value of $F - 4.9$. As this value is larger than the table value at the 1% level of significance, we conclude that the between inspector variability is significant. The inspector differences may then be compared using a linear contrast technique and judgement made accordingly.

The following example will illustrate the use of a ranking technique when the "true" ranked order of parts is known and it is wished to assess an individual's judgement.

True Rank   1 2 3 4 5 6 7 8 9 10
Inspector's Rank 1 6 7 5 9 3 2 4 10 8

$$\rho = 1 - \frac{6\sum d^2}{n^3 - n} = 1 - \frac{6(0^2 + 4^2 + 4^2 + 4^2 + 1^2 + ...)}{10^3 - 10}$$

$$\rho = 1 - \frac{6(104)}{990} = 1 - \frac{624}{990} = 1 - .63 = .37$$

ρ = Spearman's rank correlation coefficient.

d = difference between the true rank and the inspector's rank.
n = number of items ranked.

$$\text{Students } t = \rho\sqrt{\frac{n-2}{1-\rho^2}} = .37\sqrt{\frac{8}{1-(.37)2}} = .37\sqrt{9.28} \qquad t = 1.12$$

At the 1% level the table value is 3.555. A value as large as 1.397 could have occurred by change 20% of the time so this inspector has poor discrimination powers.

Inspectors variability evaluation methods of this type have several important advantages:

1. The best inspectors can be determined and they can be placed in the critical inspection areas.

2. The poorest inspectors can be replaced or they can be assigned duties in less critical areas.

3. If the within inspector variability is large, studies can be made to determine the reasons.

4. Management's rating of the individual inspectors is put on a scientific basis.

CONCLUSION

It is hoped that some of the basic viewpoints and ideas covered in this paper will prove of aid to you in visual inspection areas. They have been of significant help to the Brown-Lipe-Chapin Division of General Motors Corporation in our visual inspection areas. The writer feels that the application of statistical methods to visual inspection areas has only begun and is vitally interested in other investigators efforts in this field.

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VALUE ANALYSIS AND ENGINEERING

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QUALITY CONTROL AND VALUE ANALYSIS

As the technology of Quality Control rose from economic need, so has the growing technology of Value Analysis.

As the objective, in very general terms, of the Quality Control Program has been to assure that the product accomplishes the functions the customer wants--well and reliably, so the general objective of Value Analysis is to assure that the functions which the customer wants are accomplished at appropriate costs.

In preparing for this discussion with you, I asked a sampling of people two questions:

1. What do you mean when you say a product has good quality?
2. What do you mean when you say a product has good value?

The consensus of the answers was this:

1. If a product...

    "does what I expect it to
    as long as I expect it to...

                  it has good quality."

2. If a product...

    "does what I expect it to
    as long as I expect it to...
    and - costs what I think it should...

                  it has good value."

These simple statements will confirm the more sophisticated charter which started the research work resulting in the techniques of Value Analysis a few years ago.

The objective was to develop techniques which would keep quality, safety factors and customer features but more efficiently and effectively provide appropriate costs.

LOWER COST AND BETTER QUALITY

As the special techniques were developed, it was a gratifying surprise to find that they improved value two ways -- one by lowering costs, a second by improving quality.

A pattern of techniques based upon product or service "function" developed. The Value Analysis process started with a clear understanding of the function or functions desired by the customer, separated and classified each, provided a system for generating alternative means for accomplishing the functions, means for establishing the dollar value of each, and techniques for overcoming the stoppers and "roadblocks" encountered.

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It became very understandable that these techniques and the associated special knowledge which promoted a clear view of the desired functions, then provided alternative solutions, not only bring forth for review solutions that are lower in cost, but also many that are better in quality, more simple, and more reliable.

Experience in a recent Value Analysis technique-training course will be of special interest to Quality Control people.

Training is of a teach-learn-do type. Seventy-five men in twenty-five groups of three, each had product assemblies or production problems to which they applied the Value Analysis techniques as they learned them. The projects of twenty-two of the groups left nothing to be desired in quality. They accomplished their functions well, constantly, and reliably--the only needed improvement was lower costs. To three of the groups, however, were provided projects which, although accomplishing the desired function, were sometimes troublesome. These men were challenged to use the techniques to eliminate the troublesome and unreliable features even to the extent, if needed, of adding $10,000 per year per project to the cost. All three completely ended the quality problems in their projects providing simpler, better, lower-cost means for accomplishing the functions and all three at lower costs.

To provide basic understanding of this new technology, some orientation follows.

VALUE ANALYSIS ORIENTATION

Let's distinguish between two types of "value", which I will call "use" value and "esteem" value.

For example, the value of my necktie may be about $2. Now, let's separate the $2 into its parts of "use" and "esteem" value. The "use" value to me of this necktie is zero. It has no "use". Its "esteem" value is $2. I must wear it to conform to custom. If I didn't I would suffer the loss of more than $2-worth of "esteem". As a comparison, this tie clip with a value of $2 has a "use" function and an "esteem" function. The "use" function--what the tie clip does--could be reliably accomplished by a suitable pin or other simple product that would cost not over one cent. Therefore, we can roughly say its "use" value is one cent and its "esteem" value $1.99. How about the button on the shirt? If it has a total value of one cent, probably nine-tenths of it is "use" value and one-tenth is "esteem" or "appearance" value. A nail, for instance, has an even higher proportion of "use" value, approaching one hundred percent.

The Value Analysis techniques provide means for establishing the dollar value of the "use" and of the "esteem" portions of the function.

Now let's take a quick look at the so-called relationship between dollar value and cost. The value of this clock is $5. This we know because we evaluate by comparison; we have seen them around, we have bought them. Because we know what it costs, we have given it a value.

Now, let me add more cost to it. I am going to do some work on this clock, adding labor and overhead to it. Do you think that the added cost of the modification will increase the value? Watch carefully! (Smashes clock on floor.) What is the value of the clock now? It's zero, or scrap value, although its cost was increased, by labor and overhead.

Two things we learn from this demonstration:

1. There is positively no relation between cost and value. The cost has been increased, but the value decreased.

2. A sound usable base for value is function. The function capability of that clock changed!

Let us, for the time being, use this definition of value. "Value is the lowest cost to reliably accomplish a function"--where function consists of those elements which cause the product to "work" and those elements which cause a product to "sell"

Some of the approaches and techniques which Value Analysis uses are:

1. Approach--Clearly and sharply identify and understand the function, beginning with the function of the overall product, breaking it down into the functions of assemblies, then of the subassemblies, etc.

2. Technique--Evaluate this function; i.e., assign a dollar and cents figure to it which is the lowest cost to reliably accomplish the required function. This will be determined by a creative search for engineering, manufacturing, and other value alternatives which would reliably accomplish the total function together with the overall costs involved. Obviously, this evaluation will be just as good as the tools and knowledge and effectiveness of the evaluator. For example, for the function of containing 200 gallons of gasoline in a landing craft which has a useful life of eight years, what is the value? Four 50-gallon drums might cost a total of $25, but probably they wouldn't stand the environment. They would need some sort of coatings. As a first guess, let's estimate that the coatings would slightly more than double the cost. Estimate -- $60. Now we have a quick estimated value of $60 for the function. Always do this before finding out how the job is planned to be done, because it will lead to new and startlingly simple, reliable, and lowest-cost solutions. In this case, the specification actually called for specially-fabricated, special alloy tanks costing $520 each. The result was that in this procurement of tanks for 1000 ships, the cost to you and me, the taxpayers, instead of being the expected $520,000 was $80,000...and the function was indeed accomplished by using four drums with appropriate coatings just as on the preliminary evaluations, for $80 each set.

3. Another and different technique is called, "Blast, Create--then Refine." This means, get a clear mental picture of the function that is required and of the way it is planned to accomplish it. Then mentally blast this down to something that will have only a small fraction of the cost and will only partially accomplish the function or will have some of the attributes needed in the finished product. Next, creatively refine, adding increments of performance, of function, together with their increments of cost, until the product now will accomplish the total job with adequate reliability. This approach sounds simple, but it is amazingly effective. For example, in the gas tanks just used...first was the blast to the $25 drums which would not accomplish the total function; next, came a review of what must be done to provide the total function. Then followed the vital, but simple solution--coat the drums--which added only $55. So now, by the use of this step-by-step technique, the total function is provided with the same reliability for $80 instead of $520.

Eleven additional techniques are learned by the value engineer, each functioning in its own type of situation to cause the development of applicable reliable low-cost value alternatives.

One of the major problems in obtaining acceptance of Value Analysis is that men feel toward the value part of their own work as they would feel toward their artistic work in painting a picture. They have done the best they know how; there are no measurements as in "performance" engineering to tell them how good or bad their value is. They feel very emotional, edgy. The thought of anyone making suggestions which affect the value part of their job gives them the same emotions which a painter feels when he hears what he believes to be "untalented people" criticizing his art. To minimize this problem calls for lots of understanding, forethought and care.

Another major problem is the proper timing of Value Analysis effort. In research and development activities, top-grade "value" work is of great importance but has not been generally so recognized. Research and development work is substantially performance oriented. Feasibility models are made as fast as possible--the problem is to save time, not to save money. But before the production design is released for

quantity manufacture, it needs a large contribution from cost-centered, "value"-oriented engineers. It is too often the case that pressure of time and shortage of value-oriented capabilities forces the subsequent quantity manufacture of "development models", a procedure creating problems in complexity, very high cost, extra weight, and poor reliability. In order to gain time, the value work can be done in the laboratory simultaneously with the performance work.

SUMMARY

The technology of value analysis and value engineering consists of a system of techniques and of special knowledge which are used in the design concept stage, the design stage, the purchasing stage or the manufacturing stage to efficiently identify unnecessary costs so that they may be prevented or removed.

This technology is function based and operates to create alternative means for reliably accomplishing functions. By providing better answers, not only costs, but also quality and reliability are improved.

Quality control makes its major contribution to value by aiding the customer to secure appropriate, reliable and continuing performance.

Value analysis and engineering make their major contribution to value by aiding him to secure appropriate costs.

ORGANIZATION OF THE INSPECTION FUNCTION FOR MAXIMUM EFFECTIVENESS

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INTRODUCTION

How effective is your inspection function? Is it effective enough? Does your department meet the requirements of its assigned objectives? Have you asked yourself these questions lately? You have! Chances are you have already discovered that the organization structure of this portion of your department is important to its effectiveness. Take a look at your competitors or look at other departments within your own plant. Do you see some departments operating more effectively than others? There is a good probability that a direct relationship exists between effectiveness and organizational structure.

Now if you have the opinion that organizational structure is a cookbook thing - you're dead wrong. The organizational structure you need for your department can't be found on page 275 of some handbook on organizational structures. Organizational structures need to be tailored to the specific objectives of your department. Good, effective inspection functions don't just happen. They result from careful and thoughtful planning.

LOST? If you are, a little study of the problem will help to clear the air. In this paper, we are going to discuss the generally accepted principles essential to the effective organization of your department. In addition, we will illustrate the reorganization processes, by showing the step-by-step progress made by the inspection function of Honeywell's Aeronautical Division at Minneapolis in establishing an effective organizational structure for its quality assurance effort.

THE BASIC PRINCIPLES OF ORGANIZATION

Once the job of organizing or reorganizing begins, a study of the task turns up a systematic approach for the formulation of organization structure. This systematic approach recognizes the existence of a set of basic principles of organization. Employment of these principles in planning the organization structure generally results in efficiency and effectiveness; neglecting these principles, on the other hand, most often promotes deficiencies in the work of management.

This set of principles of organization must associate success with a dual achievement. It must provide for an effective, clear subdivision of management responsibilities and at the same time maintain an integrated unity in action.

F. W. Taylor, H. L. Gantt, H. Foyal and other early proponents of scientific management began to recognize the existence of specific basic principles of organization for industry late in the nineteenth century. This was preceded by many examples of definitive organization structure as evidenced by the organization of the Roman Legions, the Roman Catholic Church and most early governments.

However, long before this, we have evidence that some formal organization and delegation of authority and responsibility was necessary to achieve efficiency and effectiveness and to attain predetermined objectives. The most striking example appears in a passage in the Old Testament, EXODUS 18:13-24. In this passage Moses was faltering under the load of work in planning the mass exit of his people from the land of Egypt. He was advised by his father-in-law to "select able men from among his people and place such over them, to be rulers of thousands, rulers of hundreds, rulers of fifties, and rulers of tens". Moses took this advice and the able men "judged the people at all seasons: the hard causes they brought to Moses, but every small matter they judged themselves".

This biblical passage clearly contains many of the basic principles of organization used by today's management consultants to rejuvenate faltering and ineffective enterprises.

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Taylor's early work contributed most to establishing the first listing of basic principles of organization for industry. Since that day, additional principles have been added with many modern experts on the subject agreeing and disagreeing with the definition of each principle. All, however, agree that a set of basic principles of organization govern the effectiveness of each enterprise.

Lyndall F. Urwick, chairman of Urwick, Orr and Partners, Ltd., London, and a con-consulting specialist of considerable reknown in modern organization and management circles - clearly summarized the principles acceptable to most of the students of the field. These are as follows:[1]

PRINCIPLES OF ORGANIZATION

OBJECTIVE	Every organization and every part of every organization must be an expression of the purpose of the undertaking concerned or it is meaningless and therefore redundant.
SPECIALIZATION	The activities of every member of any organized group should be confined, as far as possible, to the performance of a single function.
COORDINATION	The purpose of organizing per se, as distinguished from the purpose of the undertaking, is to facilitate coordination; unity of effort.
SPAN OF CONTROL	No person should supervise more than five, or at most, six, direct subordinates whose work interlocks.
BALANCE	It is essential that the various units of an organization should be kept in balance.
DEFINITION	The content of each position, both the duties involved, the authority and responsibility contemplated and the relationships with other positions should be clearly defined in writing and published to all concerned.
AUTHORITY	In every organized group the supreme authority must rest somewhere. There should be a clear line of authority from the supreme authority to every individual in the group.
RESPONSIBILITY	The responsibility of the superior for the acts of his subordinate is absolute.
CORRESPONDENCE	In every position the responsibility and the authority should correspond.
CONTINUITY	REORGANIZATION is a continuous process; in every undertaking specific provision should be made for it.

PLANNING THE ORGANIZATION STRUCTURE FOR AN INSPECTION FUNCTION

In 1955, the management of the Inspection Department at Honeywell's Aeronautical Division recognized that its organization structure had not kept pace with the division's overall growth. The Aeronautical Division had grown in a relatively few years from a small Special Products Group into an independent division of approximately 6,000 employees. Furthermore, it was recognized that the complexity of the division's product line and the volume of growth would continue. At this time, the management of the Inspection Department decided to make a thorough

study of its organization structure, its purpose, and its management.

The discussion which follows illustrates the process of reorganization. Care was taken to describe the specific steps and relate them to each principle of organization as defined in preceding paragraphs. Figure 1 is an organization chart representing the organization in the years prior to the study.

AERO INSPECTION ORGANIZATION CHART
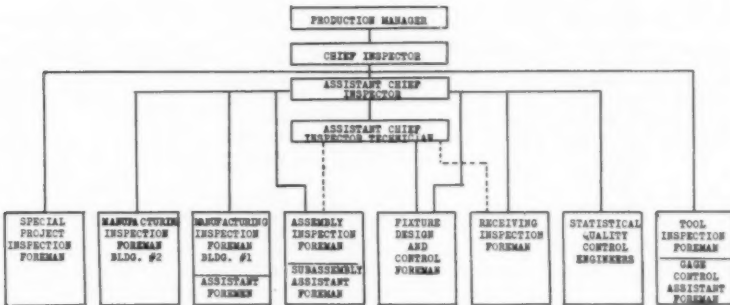MINNEAPOLIS - HONEYWELL
1950

FIGURE 1 -- Inspection Department Organization Prior to 1955-56 Study

THE PRINCIPLE OF OBJECTIVE

Don't try to develop a new organization structure until you have accurately defined the objective for the organization! Remember that each element of an enterprise must have a purpose or an objective in keeping with the objectives of the total enterprise.

To this end, the Inspection Department, under its manager's direction, began a series of staff sessions over a period of one year in 1955-56 to determine and define the objective of the Inspection Department. Figure 2 represents the final output of these sessions. It was determined that the division encountered twenty-one basic quality functions in pursuing its primary objectives as an integrated enterprise. Each of these functions were carefully defined at the conclusion of the staff sessions.

The staff immediately realized that all quality functions were not necessarily the responsibility of the Inspection Department. After tentatively establishing primary and secondary responsibilities for each quality function, they were submitted for review and criticism to the division's general manager and the department managers on his staff. The approved quality functions along with the definitions and assignments of responsibilities were distributed under the signature of the general manager.

Selecting those quality functions where the Inspection Department held primary or secondary responsibility provided the objective of the Inspection Department. This completed phase one of the reorganization.

FIGURE 2 -- Distribution of Quality Function Responsibilities

PRINCIPLE OF SPECIALIZATION

      Determine the functions for which your department has responsibility. Define
these in detail. Organize in a manner limiting the responsibility of each
member as far as possible to a single function.

      The next step taken in reorganization by the existing staff was to analyze each newly de-
fined responsibility of the Inspection Department to determine the organization structure neces-
sary to implement those functions assigned to it. It was immediately obvious that there was a
need for two sections within the department - a "line" or implementing section and a "staff" or
planning section. Evidence that this need existed in the past is illustrated by the following ex-
tract from the minutes of an early staff discussion on reorganization:

      "In the present organization the Inspection Department has its "line" organi-
zation rather clearly laid out". . . "This section now has the execution function
very definitely. However, the planning and service functions are scattered in
several loosely connected and largely uncoordinated groups. In fact, much of
the planning work is left to the line through default, i. e. no one has done any
basic planning for their jobs until the job actually reaches them. They are
forced to do the best they can under the pressures of the immediate situation."

      The reorganization discussions led to the agreement to divide the department into two
sections based on specialization of basic activities - i. e. planning vs. implementation:

              ● INSPECTION
              ● QUALITY ENGINEERING

At this point in time, recognizing the broadening scope of the Inspection Department's responsibility, division management agreed to a change in name, Quality Department, the chosen designation, included both of the new sections.

PRINCIPLE OF COORDINATION

Specialization promotes segregation of individual efforts. Provide in your organization structure some means of obtaining unity of effort.

The new organization for the Quality Department was provided with two basic sections - Inspection and Quality Engineering. This action of division of effort for specialization permitted a clear distinction between the planning and implementing functions. Each section had its specific responsibilities, but each had a clearly defined dependence on the other for continuation of its effort. Success of the department's effort depended upon both sections working together as a coordinated team. The coordination was attained by having both sections report to a quality manager. To promote more effective use of the inspection function, the quality manager was placed in a position reporting directly to the division general manager. Previously the chain of command had the quality manager, then the chief inspector, reporting to the director of production.

PRINCIPLES OF AUTHORITY, RESPONSIBILITY AND CORRESPONDENCE

Don't expect success if you are not ready to delegate sufficient authority to match the responsibility given. It is said that the definition of "hell" is delegation of a responsibility without corresponding authority.

Honeywell's twenty-one quality function study served not only as a definition of objective but also clearly designated the distribution of responsibilities within the newly organized Quality Department. Figure 3 shows the quality function responsibilities delegated to each section of the department.

INSPECTION SECTION	QUALITY ENGINEERING SECTION
PRIMARY RESPONSIBILITIES	PRIMARY RESPONSIBILITIES
● Inspection of Gages, Instrumentation and Tooling	● Collection and Distribution of Quality Data for Analysis
● Receiving Inspection of Purchased and Subcontracted Materiel	● Establishing Parts, Assemblies and Device Acceptance Procedures
● In-Process Acceptance Inspection of Manufactured and Assembled Product	● Planning and Obtaining Gages and Instrumentation
● Control of Rejected Items	● Coordination of Product Acceptance with the Customer
● Acceptance Inspection of Completed Products	● Evaluation of Customer Quality Satisfaction
	● Quality Audit of Finished Products
SECONDARY RESPONSIBILITIES	SECONDARY RESPONSIBILITIES
○ Determination of Vendor Quality Capability	○ Analysis of Contract for Quality Requirements Specified
○ Process Control During Manufacturing and Assembling Operations	○ Evaluation of Quality Capabilities of Production Facilities
	○ Corrective Action to Prevent Recurrence of Production Discrepancies
	○ Classification of Quality Characteristics for Acceptance Purposes

FIGURE 3 -- Delegation of Quality Function Responsibilities in the Quality Department

The organization structure was completed using the quality function responsibilities as a guide for its requirements, Figure 4. A letter from the division general manager introduced the new organization structure. This provided a clear expression by management of the Quality Department's "line of authority" for accomplishing its quality function responsibilities.
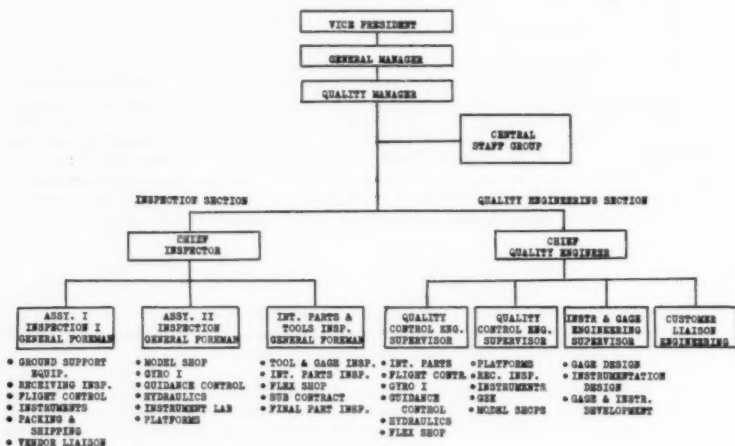

FIGURE 4 -- Quality Department Organization After 1955-56 Study

PRINCIPLE OF DEFINITION

With a definitive organization structure complete, each level of management and supervision was defined. This included: definition of the duties of the position, the authority and responsibility vested in the individual position, and the working relations between that position and the remainder of the organization. Position descriptions were prepared as necessary and procedure manuals were published to amplify on the methods used to satisfy specific responsibilities. Today an up-to-date procedural manual "QUALITY AT HONEYWELL" outlines the functioning of the department. Additional implementation appears in detailed procedures for specific areas.

PRINCIPLE OF SPAN OF CONTROL

The new organization structure limited the number of supervisors reporting into any one office to five. Each of these represent functions which essentially were related. In the earlier organization of the Inspection Department, as many as thirteen inspection areas reported to one inspection general foreman. Currently, the quality manager has two men responsible directly to him - one representing Inspection; the other with responsibility for Quality Engineering. In addition, a small central staff was recently added to compensate and plan for changing responsibilities in the total quality function.

PRINCIPLE OF BALANCE

The reorganization provided a balanced structure for assignment of responsibilities in each section of the department. Within the Inspection Section, the assembly inspection group was

split, providing two inspection general foreman positions to overcome an imbalance in the earlier organization structure. When finally completed, each of three inspection areas contained approximately 100 people reporting into an inspection general foreman.

PRINCIPLE OF CONTINUITY

"The structure of organization which is best for a concern today will not be the best in all its details a month from today, if the concern has grown as any live concern would wish to . . . continuous reorganization can no more be left to chance --- or the 'happening to think of it' --- than can routine operation. Some kind of specific provision must be made for it or it will lag behind the needs."[2]

In 1955, the Honeywell Aeronautical Division's Inspection Department was organizationally falling behind its challenge. The structure had not been made flexible enough to meet the requirements of increasing product complexity and the changing requirements of its task. Today the organization is adjusting to the changes as they occur. The most recent example has been in the area of special project quality management. This is illustrated by a "miniature" Quality Department within a department as shown in Figure 5. Today's reorganizations are a simple task, because each is made as the necessity arises.
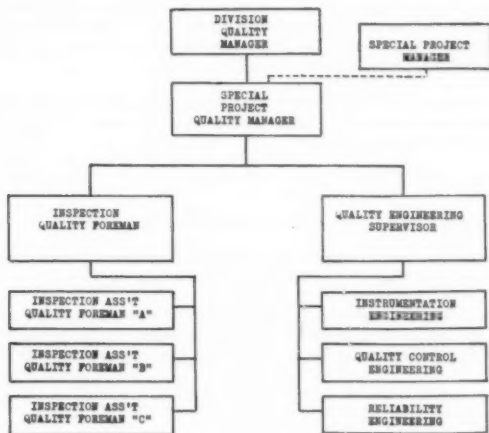
FIGURE 5 -- Example of Special Project Quality Organization

REORGANIZATION RESULTS

HONEYWELL'S 1955-56 Inspection Department reorganization allowed specialization in its two basic areas of responsibility - quality planning and inspection of product quality. Inspection supervision, freed of its responsibility for last minute planning, began to assume its more important responsibilities - supervision of personnel and control of effort. Within a short time, inspection management was in a position to make use of the services of the division's staff functions to increase its efficiency and to improve its effectiveness. The following are examples of improved conditions:

● Labor relations improved as supervision began to devote more time to its prime responsibility of supervision and work direction.

- Inspection supervisors free of the uncertainties of earlier experience of poor planning began to find time to attend management development training courses. Supervisors began to assume their proper role.

- Inspection supervision learned to make maximum use of the division's staff functions: personnel, cost control, work measurement.

- Inspector qualifications were markedly improved by a joint effort with Personnel of developing special selection and testing techniques for hiring Inspection personnel.

- Eighty per cent of the inspection positions now come under the special selection and testing program. Currently 45% of all inspectors are skilled technicians with 1200 - 2400 hours of special trade school training or equivalent.

- TEMPO, an (Total Evaluation of Management and Production Output) internal work measurement program, has been introduced throughout the inspection area permitting an inspection supervisor to analyze his groups daily output for necessary improvements in efficiency and effectiveness.

- In the newly organized Quality Engineering Section, the organization was staffed to permit concentrated specialization in several quality planning areas. Specialists in device quality planning, statistical quality control, and gage and test equipment engineering provided the advancement of the device quality management concept and better engineered test equipment. The latter activity, alone in itself, promoted increased efficiency in the inspection function.

- Today, because of the departments improved organization and increased efficiency, fewer inspection personnel are needed to do a higher volume of work at a considerably greater level of complexity.

CONCLUSION

A few words of suggestion are advisable before starting to reorganize:

- Don't reorganize until you have given the project sufficient consideration. Don't tamper with your organization with spur of the moment actions.

- Don't try to fit the organization to the people available. Whenever practical, people should, instead, be found to fit the needs of the organization. If you look carefully, you'll probably find most of the talents you need in your present organization.

- Make your organization structure clear. Fit the responsibilities expected to the authority given.

- Provide for specialization in every area possible. An individual works best when he has the greatest knowledge of his task. Make the inspection supervisor a supervisor, not a jack-of-all-trades and master of none.

- Continually review your organization structure. As changes occur, keep the organization up to the situation.

Reorganization of your inspection function and strengthening its organization structure can prove to be an important factor in improving both efficiency and effectiveness. Following the basic principles of organization, as outlined, offers a paved road to success but not a sure cure. Organizing is only one link in the chain of good management, and management is getting results through people. If you want maximum strength in your department's management, forge strong links for the other six aspects of management. Provide for a strong organization, but also provide for proper forecasting, aggressive planning, capable commanding, careful

coordinating, detailed controlling and effective communicating. People are important; don't neglect them; provide them with the tools needed to get the job done right.

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THE INSPECTION ENGINEERING APPROACH

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I would like to discuss some of the Inspection Philosophies that have been developed in the Military Procurement Functions during the past several years. I refer to them as Inspection Philosophies because they represent a siginificant change in the approach to purchase of materiel from an inspection standpoint. When we talk of trouble-shooting procurement inspection we must, in the Military sense, think of it today in terms of Military Specifications.

One of the significant changes in the approach to inspection of Military supplies has been the philosophy put forth in Department of Defense (DOD) Directives and Technical Service Regulations which establish responsibilities for inspection as being, "that the supplier shall be required to perform the examinations and tests set forth in specifications to substantiate conformance of supplies to specification requirements." The method of conveying the kind and amount of inspections to be conducted by the supplier represents another significant change in Inspection Philosophy. We now establish contractually in Section (4) of our Military Specification, a Quality Assurance system consisting of sampling plans, classification of defects, acceptable quality levels, test procedures, reference list of inspection equipment designs, and acceptance and rejection criteria. We also have established verification procedures to be used by Government Inspectors to determine the adequacy of the supplier's inspection systems. This is considerably different than the previous approaches to inspection, where in many cases the autonomy of the Government Inspector with regard to "how" he was going to inspect, "what" he was going to inspect, etc., was maintained purely from a personal interpretation of technical requirements on his part. Certainly the progress in Inspection and Quality Control diverted inspection efforts from a hererogeneous group of methods to something that has a well defined purpose. This has been brought about of course through the development of Quality Control, sampling theory, control charts, and other decision criteria which have acted as a catalyst in moulding inspection efforts into well defined purposes. So the question of trouble-shooting as we know it today, has as its basis the utilization of such documents as MIL-Q-9858, "Quality Control System Requirements", MIL-I-45208, "Military Specification Inspection Requirements, General Specification for", and other supporting documents relative to requirements for Inspection and Quality Control systems. These are the basis for trouble-shooting because they establish within the framework of the requirements, criteria of a contractual nature defining in some cases in broad terms, and in other cases in specific terms, what the Government desires in terms of Quality Assurance from the supplier.

Quality Assurance in the procurement function is of course related to the Military Specification, defining the product for service. So the essential elements then that constitute a good Quality Assurance system must be defined in detail, to support the technical requirements for the material or product for service. Here basically is a delineation of the Engineering approach to establishing a document for Quality Assurance with a proper perspective.

Specifications in the system of supply function as vital components in the procurement, manufacture, inspection, and delivery phases of the Army system of supply. In the procurement phase, the specification must detail all the requirements of the item which will enable all bidders seeking an award to calculate costs on an equitable basis, from both the Government and Contractor point of view. If all requirements are clearly and accurately stated, with no ambiguity or omissions, all bids can be presumed to be based on the delivery of comparable items, under identical conditions of inspection and acceptance standards.

From a supply and logistics standpoint, a specification is perhaps the most important document in the procurement function. We must think of this document as a repository of the necessary information to supply the using Forces with a materiel or product which they originally generated the need for. It has become a resting place of engineering effort in the form of drawings, reference documents, statistical techniques, and narrative descriptions of the skills and know-how of a great many people. It should be able to stand on its own in the procurement function as a

completely integrated document that will support the description of the product or service outlined in Section (1).

Essential considerations in the design of the specification and its related engineering drawings and documents, are that they must convey the specific details necessary to manufacture an item. Quality Assurance requirements, including all the phases of inspection and test, must be clear and specific. The Contractor should and is entitled to know in advance how Quality Assurance will be effected. The Inspector must be given all the information, equipment design, and procedures necessary to assure that the item is acceptable.

Technical and other qualitative terms may have several interpretations, or shades of meaning. Procurement contracts and the specification portions of these contracts, must be written in language clear and concise, so that it will convey the desire of the Government to prospective producers. Vagueness of meanings and implications of words and terms are vital. This is particularly important in the attitude of those engaged in the actual preparation of specifications. The legal aspects of procurement also are a part of the controls that must be borne in mind during the preparation of a specification. In order to procure acceptable service and supplies, it is necessary that the buyer and the seller come to an agreement that will stipulate exactly what is desired. The contract and the specification should represent such an agreement.

The Quality Assurance Provisions of specifications should accomplish their objective in a manner that is clear, concise, and technically adequate. The information should be clear as to intent, thereby avoiding contractual and legal controversy and providing for standardized interpretations by inspectors in different locations and plants.

The hazards to be avoided are over- or under-specification of quality assurance provisions. If over-specified, it might be impossible to procure the item, the price will be higher, the cost of inspection will be increased, and there are increased chances of Government and Contractor disagreement. If the provisions are incomplete or are under-specified, the item procured may not be as required. Some consideration in the basic structure of a quality assurance system are determined by:-

1. Degree of assurance
2. Inspection efficiency
3. Procurement patterns
4. Cost or complexity of the product
5. Method of manufacture
6. Predominant types of requirements
7. Production rate

Before deciding on a particular quality assurance system of an item, the degree of assurance necessary to insure that the requirements are being met must be determined. This is the most important factor because it will directly affect decisions for the following:

1. Number of requirements for which inspection is performed
2. Precision of measurement
3. Amount of inspection by Government personnel
4. Extent of contractor inspection
5. Severity of decision criteria

The introduction of statistical techniques, offering mathematical solutions to industrial quality problems, particularly in the complex systems field, created the need for the analytical mind in the specification field. Certainly our specifications reflect these efforts today.

A new problem area has arisen, however, in the administrative aspects of Inspection. The change in philosophy and concept which placed the inspection procedure in the Specification, namely Section (4), called for some reconsideration with regard to the approach to administratove inspection procedures. These responsibilities have been for the most part, spelled out in appropriate Orders and Handbooks. Some consideration and observations with regard to these administrative actions by responsible inspection organizations are offered as a result of experience gained since the advent of the Contractual Section (4):

1. A clear understanding of the intent of Section (4) should be predetermined prior to inspection operations. Consultation with technical personnel could resolve questions that could become points of conflict subsequently.

2. It must be remembered that the Inspector is not a Design Engineer, and interpretation of technical requirements must be avoided by him as well as substitute efforts in lieu of inadequate requirements. The Engineering Centers are responsible for Specifications. This includes the Design and Development of Section (4) (Quality Assurance Provisions). Limitations in interpretations of judgement should be practiced.

3. Efficient utilization of verification procedures, which incidentally, should where possible, include product inspection as an initial basis for judging product quality.

4. Upgrading of professionalism and maturity in Inspection Personnel is in the making and will no doubt be reflected in future inspection organizations.

I mentioned earlier the utilization of Military Specifications as trouble-shooting documents. Two basic plans specified for military procurement in the Army are:

1. Those Quality Assurance systems which are definitive in nature and are spelled out specifically within Section (4) of the specification.

2. That which requires a Quality Control system to be mandatory as part of the procurement.

In the first instance, MIL-I-45208 has been established to support the definitive type of product specification. MIL-I-45208 establishes requirements in a general sense of what constitutes an acceptable inspection system. In addition it prescribes verification procedures that will be used by the Government to determine the adequacy of this system. In the second instance, MIL-Q-9858 is designed to support the mandatory Quality Control requirements. Certainly the trouble-shooting type of inspector who is looking for a place to hang his hat, so to speak, with regards to pinpointing trouble, can in either of the preceding specifications find the necessary requirement for inspection which, when not adhered to, result in poor product. Non-conformance to these requirements is a violation of contract; hence, a trouble-shooter has a very good tool for corrective action. I do not mean to imply that the application of MIL-I-45208 in itself assures that a system is adequate. Having an adequate system in terms of people, equipment, and space is one thing. Efficient operation of that system is another. Both have to be evaluated.

A SURVEY OF VISUAL INSPECTION

Edward R. Close, Manager Quality Assurance
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The human visual system is, without doubt, the most extensively used inspection device in existence today. It is used directly as a system for testing such characteristics as color, shape, alignment, beauty defects, size and roughness. It is used indirectly in the readout system of a host of measuring systems using scales, dials, reticles and charts. The visual system is involved in almost all of the inspection decisions to accept or reject product, yet there are less than a dozen papers in quality control literature devoted to this subject.

The human visual system is a most wonderful and at the same time a most inefficient inspection device. It can detect differences in hue better than the most sensitive instruments. It can detect defects in the order of one micron in size under the proper conditions. On the other hand, given certain tasks, it may be subject to error in the order of 25% or more (1). In this day when quality costs are so important, it is time to bring the visual inspection system under firm control. Fry (2) has defined the system as having five steps:

1. Illumination of the object under test.

2. Reflection of light from the object toward the eye, and transmission of light from the object to the eye.

3. Admission of light into the eye and the distribution over the retina, which includes orienting and focusing the eye to see the object.

4. The initiation of an impression of the object in the retina and the transmission of this impression to the brain.

5. The interpretation of the impression and the use of this information in performing a task.

If we are to achieve maximum efficiency in visual inspection, we must give consideration to the entire system from the illumination of the object under test to the inspector's decision to accept or reject. Considering the five steps in the system in the order in which they occur:

1. Illumination

The I.E.S. Lighting Handbook (4) contains a wealth of data and information on this subject, and Allphin (3), Fry (2), and Weston (5) have presented further information which leads to the conclusion that there are at least three important factors which must be considered:

    a. The intensity of illumination.
    b. The wavelength composition of illumination.
    c. The contrast of the defect on the object being inspected.

2. Reflected or Transmitted Light from the Object to the Eye

References (2), (3), and (4) give quite complete coverage of this step which leads to the conclusion that the following factors are important:

    a. The direction from which the light comes.
    b. The degree to which the light is diffused.
    c. The lighting of the surrounding area.
    d. Peripheral sources of annoyance.

3. Admission of Light to the Eye and Focusing the Eye on the Object

In the control of this step in the system, the opthalmologist and optometrist can be of greatest aid. It is well known that visual acuity changes quite rapidly during certain periods of an individual's life. Experience has shown that the testing

of the inspector's ability to perform the visual task on a testing instrument such as the Ortho-Rater at six month intervals is necessary to discover inspectors who may require correction for visual acuity.

4. Transmission of the Image to the Brain

An adequate treatment of this part of the visual mechanism is beyond the scope of this discussion.

5. Interpretation of the Image by the Brain

It is in this step in the system where the Quality Control Engineer can make the greatest contribution. In order to bring this step under control it is first necessary to understand the visual inspection act which has two phases:

    a. Comparison of the product with the specification.
    b. Making a judgment as to conformance.

Specifications for visual defects take many forms. They may be actual samples of the product illustrating types of defects, or they may be prepared examples of defects such as the scratch and dig plates used as the specification for optical components. Klock (6) and Haynes (7) have described methods of specifying visual characteristics in carpets and cloth. Regardless of the form which the specification may take, the important thing is that the decision as to what the specification is, is a management decision based on the goal of customer satisfaction. The decision to accept or reject product will be made by the inspector even if a specification does not exist. This decision will reflect the management policy only to the extent that he is given management guidance.

The ability of an inspector to judge conformance to the specification has long been recognized as a major problem in the visual inspection system. Juran (8) proposed a plan for check inspection and mathematically assigning values to two kinds of inspector error:

    a. Inspector accuracy which is the percentage of defects correctly identified.
    b. Inspector waste which is the percentage of nondefectives incorrectly identified as defective.

Studies have shown that, for difficult inspection tasks with good specifications and daily check inspections, inspector accuracy is in the order of 85% to 90% and inspector waste is in the order of 1% to 3%. These studies were made on visual inspection operations which are considered to be under good control. In one inspection operation which was not under good control inspector waste was nearly 10%.

The problems of visual inspection are not easy to solve. They do not, however, constitute a dilemma. The first step in finding a solution is to recognize the visual inspection system in its entirety. The final solution will come through the knowledge of all of the sciences pertaining to the problem. These include illuminating engineering, physics, opthalmology, optometry and industrial psychology as well as quality control engineering.

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DIAL INDICATOR SERVICE AND COST CONTROL

Frank M. Dixson, Foreman, Gage Control
Standard Pressed Steel Company, Jenkintown, Pa.

(Ed. note) A detailed transcript of Mr. Dixson's remarks was not available for complete printing at the time these papers were printed. Mr. Dixson, however, will cover the following subjects as related to a large manufacturing concern, well known for its exceptionally high standards of quality combined with manufacturing quantities from small lot "specials" to infinitely large mass production on semi-automatic and fully automated manufacturing equipment.

1. The Dial Indicator and its performance
2. Checking - Range - Magnification
3. Maintenance - Cause - Abuse
4. Facts pertaining to Cost Control.

ASQC LCS Code 700:70:000

DIAL GAGE MAINTENANCE, REPAIR & CALIBRATION

W. G. Arnold, Superintendent, Factory Engineering
S. K. F. Industries, Philadelphia, Pa.

In the two Philadelphia plants of S. K. F. Industries there are in daily use some 3,500 dial indicators. The manufacturing tolerance on most of our products are finer than used in many tool rooms throughout the area. The metric system is used exclusively in our plants and most of our grinding tolerance are expressed in microns. A micron is equivalent to two and one half "tenths" (ten thousandths of an inch). To guarantee the high quality of precision necessary in our business it is not difficult to see that a first class system of Dial Indicator Gage Maintenance repair and calibration is an absolute necessity.

All indicators in use, or any new ones to be put in use, are numbered and a record established in a card file kept in the Gage Standards Room. One instrument maker (first class) is located in this room and spends his full time checking and repairing indicators. After the indicators are accepted from the supplier and put in use, periodic checks are made to see if any repairs are necessary. These checks are recorded on the record cards for the individual indicators and the frequency of the future checks are determined by the past history on the card. In addition, frequent visual inspections are required from all personnel using indicators for such obvious defects as broken or unstable plungers and bent or worn indicator points.

The general periodic check schedule, unless card history dictates more frequent checks, is as follows:

> All .001mm and .002mm indicators are inspected once a month;
> .0001" once every two months; and
> .005mm and .01mm every six months

All newly purchased indicators must pass the following "Acceptance Specifications"-

(1) **Repetition of Readings** - Reading at any point, as for instance when checked in a U. D. fixture, shall be reproducible through successive movement of the spindle to plus or minus 1/5 graduation.

(2) **Accuracy of Calibration** - The dial indicator, when checked in a master gage, shall be accurate to within one graduation, plus or minus, at any point of the dial from the approximate 10 o'clock position to the final 2 o'clock position. (Approximately 2-1/3 turns on Model #381 or similar type).

(3) **Sensitivity** - By sensitivity we refer to the ability of a dial indicator to register as nearly as possible the full value of a small eccentric specimen - or a known dip in a Jo-Block when passed slowly under the contact point. The values should be as follows:

> For Micronar - At least 80% of a 4 micron dip = 3.2 micron;
> For #381 or similar - At least 75% of a 6 micron dip = 4.5 micron.

(4) **Variation in Plunger Pressure** - By this we refer to the difference in pressure required to move the plunger inward as against the pressure exerted against the work when plunger moves outward. In all instances it always requires greater pressure to move the plunger inward. We are not so concerned about the actual pressure unless it should happen to be way out of line with other similar indicators. This test can be conducted in the following manner:

ASQC LCS Code 700:70:000

(a) Fasten indicator to bracket on special height gage stand kept in the Gage Room. (b) Place torsion scale under pointer and bring bracket downward by means of lead screw. (c) Note how many grams pressure was required before the indicator hand starts to move. (d) Continue the downward movement until the full range of the clock is reached. Notice the reading on the scale at this point (which will be considerably higher than when the hand first started to move). The difference in readings between these two points shows how many grams pressure was required to move the spindle inward its full length. (e) Reverse the travel of the bracket whereby the scale gradually becomes unloaded. Again notice that the scale has to be unloaded quite a bit before the indicator hand starts to move back, but once it starts to move it does not take much more unloading of the scale before the hand is back at its rest position. The total difference in reading at any point should not exceed 125 grams for #381 or similar dial indicator and 50 grams for the Micronar.

Gage manufacturers in general do not guarantee sensitivity and plunger pressure because it is not covered in the "The American Gauge Design Specifications". The Standard Gage Company, however, from whom we buy most of our indicators, has agreed to test all indicators for S. K. F. according to the above mentioned specifications.

In regard to Mikrokators, we do not have any specifications set up for these instruments because they are generally made so accurately that we have never found any discrepancy between any of them. However, when received they are checked on a special gage for calibration against a Mikrokator kept as a master in the Gage Room.

Periodic inspection records indicate that the majority of service required falls in the category of cleaning, dial replacement, and crystal replacement. Our standards room, however, is fully stocked with complete spare parts inventory and our instrument maker is capable of making any type of repairs. It has been our experience that, with proper care and maintenance, the life of an indicator is (for all practical purposes) infinite. A good many of our indicators are still in use from the time we started keeping records about twenty years ago.

In order to give you some idea of the cost involved in a program of this type, I have taken the simple expediency of dividing the sum of labor and overhead, parts purchased per year, and stationary costs divided by the number of indicators passing through the standards room in one year; this figure come to approximately $3.80 per indicator per year.

In view of the fact that 90% of the dial indicators used in our production and inspection are of the comparator type, using accurate and expensive zeroing masters, the indicating mechanism is of prime importance. Therefore we consider this nominal cost of maintenance and control money well spent.

COST CONTROL AND QUALITY CONTROL OF DIAL INDICATORS

Murray P. Dwight, President
Dwight Instrument Co., Lyndhurst, New Jersey
(Dwight Instrument Co. is an independent repair shop specializing in dial indicators.)

For those of you who are with companies having 1,000 employees or less, maintaining a quality repair shop at an economical cost becomes a problem of volume as well as control somewhat different from that of the large company.

For this repair facility to prove itself economically, about six indicators per working day should be overhauled. This would include those which need just cleaning as well as those which also need parts. This number is based on an estimate of $100.00 per week pay for the repair man plus $150.00 per week in overhead charge, or a total for the year of $12,500.00. Six indicators per day then works out to around 1,450 per year. With this volume moving through the repair shop, the cost per indicator is between $8.00 and $9.00, or close to the average charge if these indicators are sent to an outside repair shop for service. However, if you have less than the 1,450 indicators needing overhaul, and if your shop is flexible and control of your work force is tight, you can have your repair man do jobs in the tool room or other areas when there is no need of indicator repair. A schedule should be maintained, and for each day spent, six indicators should be properly overhauled, inspected and put back in the gage crib; the less a man does this work, the more difficult it is to maintain a proper schedule of quality work.

If, using these figures as a starting point for your cost of setting up your repair facility, you find that it is economical, you need to take the following steps:

(1) A clean area with proper calibrating equipment must be maintained. This cost will be a minimum of $500. It covers the cost of benches, lights and fixtures and a small surface plate. Also included is a calibrating fixture which may be purchased for about $100.00 and a set of approximately thirty gage blocks which can be obtained for $150.00.

(2) Next, a man must be properly trained. All the manufacturers of dial indicators are pleased to have your man spend a week or more in their plant, familiarizing himself with the methods and parts necessary for proper repair.

(3) Parts needed must be ordered and an inventory system set up for these parts. It is from here on that your controls must be established, and these controls must be a part time job of men working in various departments of your plant.

(4) The flow of indicators into and out of this facility must be the responsibility of your gage crib. If this is not done, some indicators may enter the repair shop but will never come out.

(5) Inspection must be made on each indicator after repair by the inspection department before it is allowed back on the shelf in the gage crib.

(6) The inventory of parts must be kept the same way as any inventory throughout your plant with the repair man responsible for any undue loss.

If you have the volume average of six indicators per working day, and you are able to set up these controls, you can maintain a high level of quality and fast service on your indicators at a reasonable cost.

Here the question arises relative to the cost as well as the inconvenience of sending an indicator out for repair. You will note that I have not as yet mentioned the

cost of ordering parts; but, if it costs money to send an indicator out for repair, it also costs nearly as much to process an order for parts. And in our experience, you often have to buy less than $10. -worth of parts, without which you cannot repair 50% of your indicators. Examples would be contact points, bezel screws and the like.

If you decide to send your indicators out for repair, you have a dollar cost of this charge and can see exactly how much this is with respect to your over-all gaging program. You must, of course, maintain inspection on the indicators when they come back from repair, no matter where they are sent, so that you can reject then and there those which do not measure up. However, your rejection rate should be less than 1%.

If you send these indicators back to the manufacturer, you will be assured of high quality work at a reasonable price. There is also the independent instrument repair shop which does business with many companies such as yours.

A typical independent repair company will have five or six employees. The company repairs all makes and models of indicators as well as measuring instruments. A stock of parts is maintained to cover all the common makes. The men become highly skilled to do quality repair work and do it fast so that the cost to you will be reasonable, and the repair company will still make a profit. In most respects, this company is operated much like the repair facility in the large plant, with the added cost of sales expense but a much lower overhead all told.

There is a great variety of work which comes into these independent shops. One, turning out 200 items per week with a back-log of two weeks' work, will have 150 different types of instruments to repair. One or two men, usually the foreman or the owner, work on the less common items which come constantly in quantities of one or two. This would possibly be a rarely seen foreign indicator or one of an American manufacture (obsolete type), twenty to thirty years old, but still in good enough condition to warrant repair.

This independent repair company can offer you the same service as the various manufacturers in repair, but with some added advantages to you:

1) All makes and models may be sent to one source, thus eliminating the problem of splitting up the items needed for repair and sending them to the various manufacturers around the country. This one source reduces to a minimum the cost of paper-work and order processing within your plant.

2) If you use a quantity of a special type indicator, the repair company will soon have in stock those parts needed to repair even large numbers of this particular type, ensuring you prompt deliveries.

3) Cost of repair can be set up by written or verbal agreement so that you will know in advance how much you will be charged, on the average, for repairs. This is done by specifying a repair cost not to exceed, for example, 50% the price of a new indicator. Or if you wish to have a dollar figure fixed for each item, this can be done after the repair company has had some experience on the condition of your indicators which are sent to them. This figure could be $8.50 for your company but maybe $9.00 for another company. The repair company has the option to return an indicator at no charge if they feel that it definitely is not economical to repair.

But whether you send your indicators back to the manufacturer or to a repair company, you must inspect each indicator when it is returned, and make sure that information is properly noted on your inventory and quality control card for each indicator; obviously, it is an advantage to have a serial number on each indicator.

As I have discussed it here, the maintenance and repair problem (cost control and quality control) of dial indicators may be summed up as follows:

(1) If your plant has a volume of around 1,450 indicators per year which need cleaning or repair, a shop in your own plant may be well justified economically. You must, to maintain quality, have an experienced man whose work is inspected by another person and the flow of repairs should be controlled by another person to insure that an indicator will not get into the repair room and never come out.

If these conditions cannot be met it is expedient to send all repairs to an outside shop, either to the manufacturer or to an instrument repair shop. When this is done, all of the above requirements are carried out automatically; (1) you have the paper work on what indicators are out and how long they have been out; (2) you do not have to maintain a stock of parts with the corresponding cost of inventory records needed to control this stock; (3) the indicators are inspected when returned before going into stock and (4) you then have, on paper, a control of cost and quality on your dial indicator servicing.

MEN--CIVILIZATION--MEASUREMENT

M. C. Curtis, General Foreman, Tool Inspection
The Timken Roller Bearing Company, Canton 6, Ohio

Measuring or gaging is a very important part of manufacturing. This discussion will be limited to linear and angular measurements.

History indicates that as we improve our ability to measure, our standard of living improves.

In the 14th century, parts of the human body were used as standards of length. The first 16 men to leave church on Sunday morning were lined with the left foot, heel to toe, and the distance from the toe of the first person to the heel of the last was considered the legal rod.

The cubit was one of the first known measurements. We are told that there were two -- one 18" and one 20". Two-thirds of the 18" cubit was divided into 12 equal parts and called an inch. Obviously standards of this type would not suffice for present day practice.

All measurements are relative. They must be compared with some known standard; for example, a steel rule, a precision gage block, or a light wave.

Unless we can describe a manufactured part in terms of numbers, it cannot be fully described. It is not enough to say that it is large or

FIGURE 1 -- The Timken Company Gage Laboratory is the best equipped industrial gage laboratory in the United States. This laboratory is temperature, dust and humidity controlled. Thirty people are employed here.

FIGURE 2 -- Individually wired desks are used for work benches in the
Timken Company Gage Lab. One hundred and twelve people are employed in
the entire Tool Inspection Department which controls approximately
500,000 tools and gages including 4,000 reference gages.

small or round or square; it must be identified in terms of inches,
angles, radii, and so forth.

All things man made must be measured. They must be measured in
some manner, although some measurements are crude and some are refined.
Highly precise measurements today may be considered crude in the future.

George Washington University, one of our leading institutions of
higher learning, has formally recognized the importance of accurate
measurements by offering a course on the subject. I think it is
timely and will make possible, for those who are interested in measuring,
an effective means of obtaining information on the subject that would
be difficult to obtain in the usual manner.

The difficulty of training men in the skill of measuring can be
appreciated when I tell you that we obtain our tool inspectors through
an apprentice training program requiring four years. This training
program takes the apprentices through all departments of our bearing
factory, including the tool cribs, screw machine departments, grinding
department, inspection department, tool room and the engineering
department. They finish in the gage laboratory. It is here that the
patient, painstaking task of measuring parts accurately begins.

Parts must be measured to the proper degree of accuracy. We would
not attempt to measure a part 100" diameter to a tolerance of 10
millionths. We would not measure a rough casting with a highly precise
gage that might be graduated in terms of millionths. It would not be
good practice to attempt to measure a highly precise part with an
instrument that would read in terms of fractions of an inch; therefore,
it becomes necessary to select the proper equipment for the job.

We use for a tolerance on our masters and gages an unwritten rule of 1/10 of the permissible tolerance allowed on the part to be gaged. If the part has a permissible tolerance of 1 ten-thousandth of an inch, the tolerance on the master or setting gage should be 10 millionths of an inch. By comparison, we have made many gages over the past several years to this degree of accuracy. We are fortunate in dealing mostly with tapered parts that make it possible for us to work to this degree of accuracy, that is, 10 millionths of an inch. Usually we can grind a gage round and straight, and with

FIGURE 4 -- A Bausch & Lomb universal projector is used in checking a wide variety of jobs including threads, radii and profile gages.
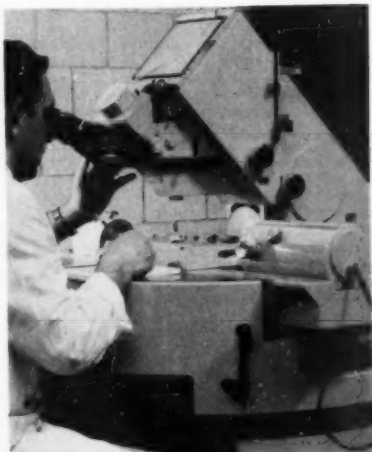
FIGURE 3 -- The Zeiss Universal Measuring Microscope is considered most versatile gage in the Tinken Company's Gage Laboratory. The machine is used primarily for checking accuracy of tool profile gages necessary for grinding of forming tools used on automatic screw machines.

the proper surface finish on a tapered part, then face until we arrive at the proper size.

Go and No-go gages have their place in the business and they are economical to manufacture, but may be costly, too, in the long run. A Go or No-go plain plug gage will either enter a hole or it will not enter. If it does enter, it will not indicate out of round that may be present. It is difficult to determine the amount, if any, of bellmouth or taper and will not indicate the difference that may exist from basic size. Indicating type equipment could show the amount of out of round, taper, or bellmouth and show the difference between the size and basic size. Indicating equipment makes it possible to set cutting tools to the best advantage. As the tool wears and causes the part to increase or decrease in size, it can be set to obtain a maximum tool life before sharpening.

Progress in our ability to compare parts with master gages or

precision gage blocks has improved considerably in the last few years.

Many types of comparator gages such as dial indicators, optical comparator type gages, pneumatic gages and electronic gages have been developed to a high degree of accuracy. The mechanical indicator is used extensively for many operations. It is a very reliable, dependable, economical, and practical method of comparing and gaging manufactured parts.

Pneumatic type gages have their place in comparing parts with a part of known size, shape, and accuracy. They are especially useful where it is possible to fixture for the gauging operation. They are well suited for comparing parts with thin walls, parts with a highly polished surface. The life of the master or setting gage is extremely good because of the fact that it will not become scratched and is subject to little wear. Pneumatic gages are especially adapted to comparing parts with a tolerance of 5 thousandths of an inch or less. Where tolerances are less than 1 ten-thousandth of an inch, electronic gages are more practical.

There are many electronic gages built today with a high degree of accuracy and reliability. Electronic gages are best suited where tolerances are in the order of the low millionths of an inch. We use many electronic gages throughout our plant on the production line as well as in our gage laboratory. Electronic gages are not 100% electronic. Since pickup is usually mechanical, the gage will be only
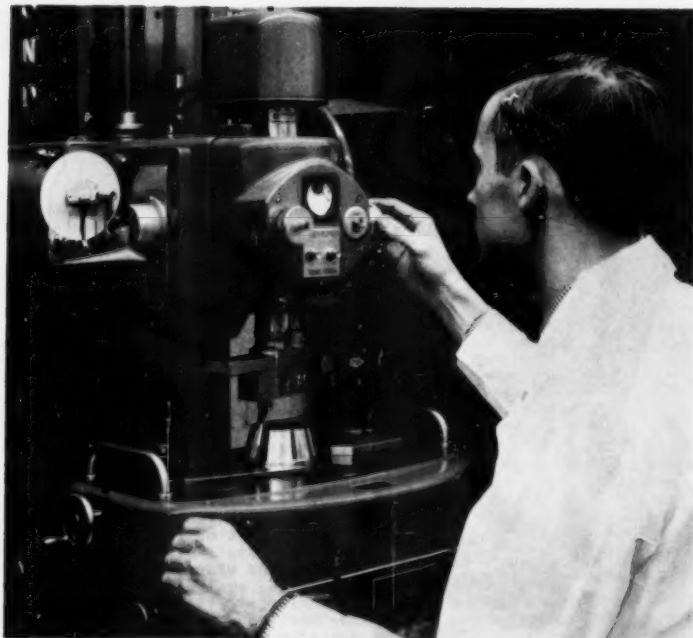
FIGURE 5 -- The Talyrond is a gage designed for checking roundness of machine parts to an accuracy of one millionth of an inch. It not only shows the degree of roundness but it also indicates the shape of the out-of-round part.
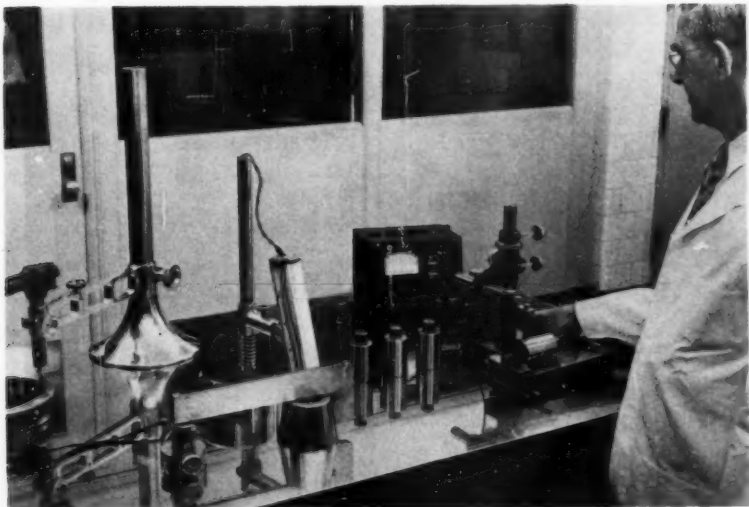
FIGURE 6 -- On this Graph-Mo surface plate, the operator is checking a
roller master for size and taper. At left (rear), Graph-Mo ring gage
is checked for length. Cone taper gage is checked for taper in center
foreground. It is one of the flattest plates of its size in the world --
within 50 millionths.

as good as the mechanical part of the gage.

We have cylindrical grinders for grinding both inside and outside
diameters. They are capable of grinding to round within 2 millionths
of an inch, straight to the same degree of accuracy, with surface
finish as low as 1 micro inch.

Four factors are required to achieve this high degree of grinding
accuracy: We must have a machine with this capability; have an effi-
cient operator; the environment must be right, and we must have the
proper material with which to work. We could not expect to attain this
degree of accuracy with a machine that is not in good condition. The
machine must be as nearly free from vibration as possible, table ways
must be straight, motor and motor pulleys must be properly balanced,
the wheel must be dressed where it contacts the work, a good diamond
must be used. The dressing diamond should be a ground conical diamond.
The operator should be sufficiently skilled to obtain from the machine
its full capability. The environment must be right, or we cannot expect
to grind to a high degree of accuracy.

The machine must be mounted on a vibration-free base; the
temperature should be controlled in a room with a minimum amount of
noise. The room must be as free from vibration as possible, as
vibration is one of the greatest enemies of high precision grinding.

Steel is not an inert material. It changes size and shape with a
change of temperature. This is characteristic of steel and cannot be
altered. It is resilient, it sometimes sags from its own weight. A
cylindrical piece will deform elastically when it lays on its
periphery, therefore, care must be exercised in order to avoid dis-
tortion. Distortion can also result from too much gauging pressure or
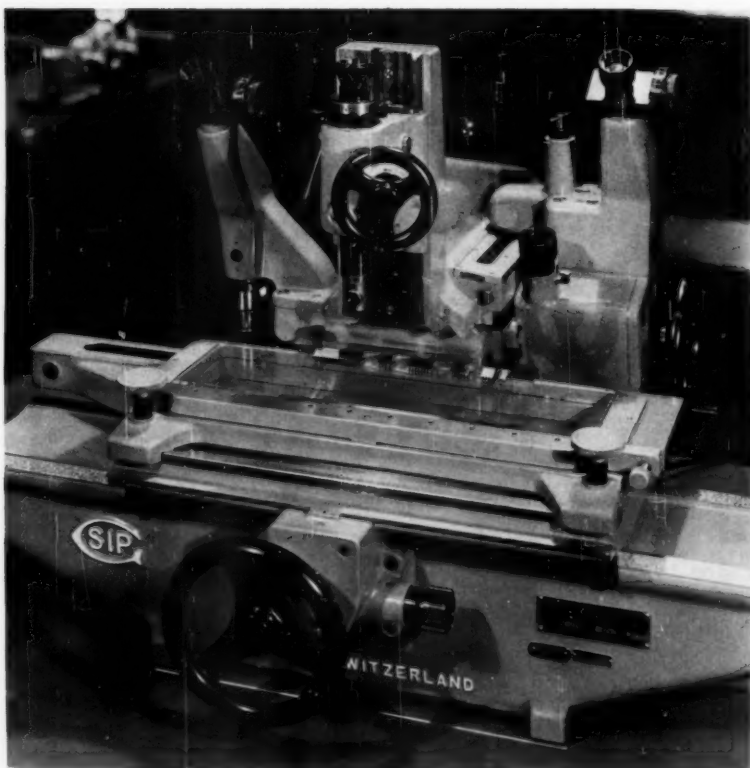by the way in which the piece is held during the gauging operation.

FIGURE 7 -- A SCIP MUL 214 with a 4 x 16-inch capacity, universal three
dimensional measuring machine. It will measure the pitch diameter,
round, straight and bellmouth of internal threads. Accurate to within
twenty millionths of an inch.

     Temperature is very important. Unless the piece is gaged at the
international temperature of 68°, or unless the temperature is known
and compensated for, we cannot expect to obtain the proper degree of
accuracy. Steel changes at the rate of 6-1/2 millionths per inch per
degree.

     Stress becomes a very important factor in obtaining a high degree
of accuracy. Materials should be as nearly free from stress as
possible. We are aware of the fact that we set up stress in the piece
when we grind. At the same time, we may relieve stress during the
grinding operation. It is possible to finish one part of the piece
to the required degree of accuracy only to have it change when another
part of the same piece on another operation may cause the first part
to change. We used to believe that we were relieving stress during a
hand lapping operation. We have found out now that we do not relieve
stress but produce more stress during the hand lapping operation.

Foreign particles such as dust, dirt and lint, always present, are one of our greatest enemies in trying to achieve high precision gauging. Every effort should be made to have the part to be gaged as nearly clean as possible.

Surface finish is another important factor in gauging to a high degree of accuracy. We cannot hope to measure in the low millionths a surface whose finish is rough and irregular. In order to determine the size, it is necessary for it to be round, straight, and free from irregularities. This is true of cylindrical work. The same applies to flat work. Unless it is flat and the surface sufficiently regular, free from taper, we cannot expect to measure to a high degree of accuracy.

Surface finish is probably the most difficult measurement. Most surface finish checking gages do not show waviness. It is difficult to determine where roughness leaves off and waviness begins. Few if any of our surface measuring instruments show the exact profile of the surface finish. Surface finish can differ in profile and it will not be shown on the read-out. Surface finish measurement is not a true measurement. It is an average deviation in height as determined by a stylus with a 5 ten-thousandth radius and propelled over the surface at a speed that will determine the roughness width cut off. The reading might change radically with a change in roughness width cut off. The vertical magnification is much higher than the horizontal magnification. Since the read-out is distorted, it is not a true indication of the surface finish profile.

In order to obtain the desired accuracy on a finished part, it is necessary to start as nearly precise as possible. It is necessary to be as nearly right on the absolute check as possible. Each time a comparison is made, there is a possibility of losing accuracy. (If we err on the absolute check with an interferometer when checking precision gage blocks, then err between the gage block and the master gage and again err between the master gage and setting the comparator and again when the gage is read, then we may finish with all these errors in the final result.)

I have mentioned the fact that we have improved our ability to machine, and that we have comparators capable of a very high degree of accuracy. Until 1952, however, little progress had been made in precision gage block accuracy. The tolerances at that time for precision gage blocks had not improved in over 25 years. The tolerance

FIGURE 8 -- The Link fringecount micrometer: a combination interferometer and electric counter. It is possible to determine absolute length to an accuracy of one millionth of an inch and can measure lengths up to two inches.

for "AA" quality blocks was plus or minus 2 millionths; for "A" quality, plus or minus 4 millionths, and for "B" quality, plus or minus 8 millionths of an inch. We felt that "AA" quality precision gage blocks (the practical standard used through the world), should be within 1/2 millionth of an inch. In order to accomplish 1/2 millionth accuracy in precision gage blocks, the absolute interferometer should have capabilities in the order of 1 ten-millionth of an inch to accomplish 1/2 millionth measurements. The project to improve standards of accuracy was started at that time by a group of interested manufacturers. Money was received from the congress and the job was undertaken by the National Bureau of Standards in Washington. The project is now under way and will take a few years to complete. In the meantime, manufacturers have produced precision gage blocks to a guaranteed accuracy of 1 millionth of an inch.

For the past 70 years our standard for length has been a platinum-iridium bar on which two lines are scribed one meter apart. The number of light waves that appear between these two lines were counted and a value assigned to the light wave. There were a number of light sources that could be used for this purpose. Recently it was agreed internationally that the orange-red line in krypton 86 will be used in the future. Using this light source, there are 1,650,763.73 light waves in one meter of length.

The interferometer is an optical gage with a monochromatic light source with which we can determine the absolute length. Our Bureau of Standards has partly completed an interferometer that it is hoped will have a capability of measuring to 1 or 2 tenths of a millionth.

Separating the concept of a rod as a unit of measure and the interferometer is six hundred years. Over that period of six centuries a constant refining process has taken place. Within the past twenty years important steps have been taken to further refine our ability to measure accurately. Positioned as we are on the threshold of space exploration and travel, accuracy takes on even greater importance. It may well be that the ability to measure accurately can spell the difference in the mighty struggle between East and West that is taking place, even as we meet here. Thank you.

ADVANCED TRENDS IN ELECTRIC GAGING

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Two years ago, Industrial Products personnel at the Hamilton Watch Company realized there was a growing demand for a simple, highly reliable, and very accurate Gaging System that could be applied to industrial processes to reduce the cost of parts fabrication and inspection. Developmental work was undertaken, at that time, and the result today is a system known as Electric Gaging. This paper will define Electric Gaging; it will describe the function of the Electric Indicator and control units; and it will describe typical applications of Electric Gaging to reduce the cost of parts fabrication and inspection.

DEFINITION OF ELECTRIC GAGING

Electric Gaging is a Measurement System, utilizing an Electric Indicator and suitable control equipment to provide an electrical signal whenever pre-established dimensional limits or tolerances are exceeded. The Electric Indicator portion of the system is a high precision limit switch which, when adequately fixtured, is capable of measuring a particular dimension on a part in providing a switch closure when the actual dimension measured is above or below pre-established limits. To convert the indicator switch closure to a useful output signal, a control unit is used in conjunction with the Electric Indicator. Selection of the control unit depends upon the requirements of the application in question.

FUNCTION OF THE ELECTRIC INDICATOR

The Electric Indicator resembles a Mechanical Dial Indicator in that it has a spindle, gear train, and rather conventional housing. It differs from a Mechanical Indicator in that two adjustable electrical contacts are built into the movement to provide the switching actions. Also, there are two adjusting screws (high and low tolerance) to set the dimension at which switching action will take place.

Technically, the Electric Indicator is a high precision SPDT switch. It differs from an ordinary switch in that there is amplification (approximately 100X) between the activating mechanism (spindle in this case) and the switch contacts. This amplification is the reason the Electric Indicator will repeat a dimensional reading electrically to better than ten-millionths of an inch.

An ordinary set of switch contacts will repeat a dimensional reading electrically to better than 0.001", therefore, it is safe to assume that the contacts in the Electric Indicator repeat at least that well. Between the contacts and the spindle there is 100X amplification through the gear train and, therefore, the Electric Indicator will repeat to ten-millionths of an inch (0.001" $\div$ 100 = 0.00001").

Laboratory and field tests of the Electric Indicator have shown that the unit will repeat electrically to better than ten-millionths over extended periods of use.

FIGURE 1 -- Electric Indicator

FUNCTION OF THE BASIC LIGHT BOX

The Basic Light Box is designed to be used in conjunction with the Electric Indicator to convert a switch closure in the Electric Indicator to a visual signal (consisting of three lights) that can be seen by an operator. If the measurement being taken is either higher or lower than the pre-established limits, the appropriate "out-of-tolerance" light will go on.

To turn on any one of three lights in the Basic Light Box with the SPDT switch in the Electric Indicator is somewhat of a trick without using auxiliary switching devices, such as relays. This problem is solved with the use of a low voltage bridge circuit. Figure 2 is a Schematic Diagram of this circuit. A switch closure in the Electric Indicator will add a resistance (out-of-tolerance lamp) in parallel with the fixed resistor and the "in-tolerance" lamp. With this added resistance, the voltage drop across the "in-tolerance" lamp is reduced nearly to zero and the light goes out.

FUNCTION OF THE AMPLIFIER CONTROL BOX

In automatic gaging and machine control applications, where it is necessary to switch voltage and current in excess of the safe values for the contacts inside the Electric Indicator, an amplifier is employed so that a very low level signal from the Electric Indicator will activate a relay capable of switching 10 amps at 110 volts, resistive.

Figure 3 shows a dual channel vacuum type amplifier commonly employed in automatic gaging. A similar amplifier, utilizing two transistors instead of the tube, is available for customers who prefer this type. The application of the two units is identical.
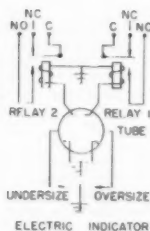
There are several other circuits available for control applications where memory, counting, or timing functions are required. They will not be described because their use depend upon specific gaging or control problems.

FIGURE 2 -- Basic Light Box

FIGURE 3 -- Amplifier Control Box

APPLICATIONS OF ELECTRIC GAGING SYSTEMS

Electric Gaging can be applied in two basic ways. One is to fabricate a part and then measure its dimensions, either manually or automatically. The other is to integrate Electric Gaging with a machine tool to control size as the part is being fabricated.

In the first method, "in-tolerance" parts are separated from "out-of-tolerance" parts while in the second method only "in-tolerance" parts can be fabricated (assuming the machine tool is functioning properly). It is fairly certain that there is a demand for both types of Electric Gaging, therefore, the applications will cover both major areas.
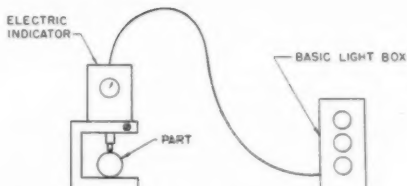
POST PROCESS GAGING

FIGURE 4 -- Manual Gaging

Electric Gaging can be used to advantage in measuring either single or multiple dimensions on a part after it has been fabricated. Figure 4 shows a typical application where a part is hand fed into a measurement station and the operator reads lights (over, good, under) instead of a dial. There are several advantages to using Electric Gaging on this type application when compared with using a conventional dial gage. Not only can an operator read lights faster than he can read a dial, but nearly all judgement is removed from the job because the Gaging System decides whether the dimension being measured is "in" or "out-of-tolerance".
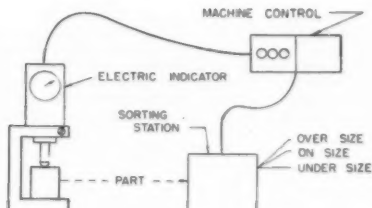

FIGURE 5 -- Automatic Gaging & Sorting

Figure 5 shows another application of post-process gaging where the Electric Gaging System is used in conjunction with automatic feeding and sorting devices. For example, parts can be hopper fed into a gaging station where one or more dimensions are measured, and then the part automatically sorted into two or three categories.
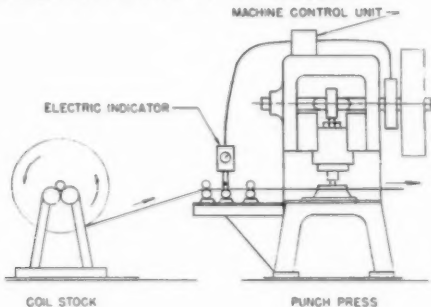
IN PROCESS MACHINE CONTROL

FIGURE 6 -- Continuous Strip Measurement

As stated above, Electric Gaging can be applied directly to machine tools to control the size of a part as it is being machined. Figure 6 shows one application where Electric Gaging is used to measure stock dimensions before it enters a machining process. For example, the thickness of strip material is measured before entering a punch press operation. If the thickness of the material is out-of-tolerance the Electric Gaging System will shut off the machine, thereby, preventing damage to the tools or preventing out-of-tolerance parts.
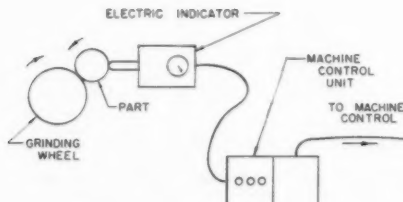

FIGURE 7 -- Size Control on a Machine Tool

A second application of Electric Gaging to machine control is shown in Figure 7. In this example, the Electric Gaging System is constantly measuring the part as it is being machined and will activate the next machine cycle when the part is on size.

CONCLUSION

From the above discussion of Electric Gaging, it can be seen that there is a place in industry for this Gaging System wherever dimensions must be accurately controlled. This Gaging System can be economically justified in manual gaging operations, automatic gaging, and automatic size control on a machine tool. It is hoped that this discussion of Electric Gaging will help Manufacturing Management personnel become more cognizant of the fact that this system is one effective way of reducing manufacturing costs.